WP 6 - Tools and guidelines for improving/designing a resilient BE assessed through case studies and virtual training

T6.2 - B-based resilience assessment of the case studies: current conditions versus simulation-based and users' training-based selected strategies, selection of the best strategies and their technical reliability, development of tools/guidelines supporting the holistic decision-making process.

DELIVERABLE ID	D6.2.1
Deliverable Title	Report on case studies simulation results
Delivery month	M23
Revision	1.0
Main partner	UNIVPM
Additional partners	
Authors of the contribution	Gabriele Bernardini (UNIVPM); Enrico Quagliarini (UNIVPM); Gessica Sparvoli (RM-UNIVPM); Federica Ameli (UNIVPM)
Deliverable type	report
Number of pages	35

Abstract

Simulation-based approaches are powerful methods for assessing risks in the built environment (BE according to a holistic perspective, since they can jointly represent the agents affecting emergency conditions (BE features, disasters feature and combination, users' typologies and reaction). The current deliverable traces the results of the application of agent-based simulation model developed by D4.1.1 on the case studies identified by D3.3.1, depending on their exposure conditions in D3.3.3. Current scenario conditions are assumed, by thus representing each BE before any additional risk-mitigation strategy. This can allow understanding the current level of risk and resilience before promoting resilience-increasing interventions. Using the methods developed in D4.2.1, simulations are organized in two main groups: 1) Slow Onset Disasters (SLODs - heatwaves and pollution implying the permanence of users in the outdoor BE) are assessed by themselves through simplified models relying on the relation between users and the BE conditions; 2) SLOD are then considered as input scenarios for Sudden Onset Disasters (SUODs) implying evacuation in (earthquake) or from (terrorist act) the BE. The specific risk associated to each assessed BE case study are considered to this end, thus avoiding redundant or not relevant risk combinations. The basic key metrics (e.g. evacuation times for SUODs; exposure time for SLODs) defined in D4.1.1 are then used to trace preliminary results from the BEs application, in view of a more extensive assessment through next actions concerning behavioural-based Key Performance Indicators (KPIs) and metrics development in T4.2.

Keywords

Resilient evaluation, SUOD, SLOD, BET, KPIs, Behavioral-based simulations.

Approvals

Role	Name	Partner	Date
Coordinator	Enrico Quagliarini	UNIVPM	-
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Revision versions

Revision	Date	Short summary of modifications	Name	Partner
0.1	22.10.2021	Deliverable structure and main content	Martha Caramia	POLIMI
0.2.	26.10.2021	Deliverable general review	Graziano Salvalai	POLIMI

Summary

1. Introduction

The BE archetypes (WP3) provide a rapid characterisation of possible ideal scenarios in terms of physical, morphological, user-related and possible risk-related parameters (WP4), as well as indications for an inventory of possible mitigation solutions for single and combined risks (WP5). The use of simulation tools, available for BETs in (D411), in pre and post-mitigation conditions, also helps to speed up the assessment and mitigation process from a multi-hazard perspective (D'Amico et al. 2021).

However, such analysis provides only a superficial summary of potential effects under ideal circumstances and needs to be further explored through an individual case study regarding its distinctive features in morphology, construction, risks, as well as the exposure and vulnerability of affected users (Quagliarini et al. 2023).

This chapter presents three case studies in Italy, illustrating the worth of the suggested approach and highlighting discrepancies between the real-life scenarios and the archetype (BET). Adhering to the project's methodology, this chapter initially defines the study setting in terms of vulnerability, hazard, and exposure features, outlining the comparison with the reference BETs. Regarding this characterisation, potential multi-hazard mitigation techniques are likewise recognized, analogous to the reference BET categorization. Finally, about the dominant hazards of the case study, evaluations of "SLOD-to-SUOD" are carried out, assessing how an emergency scenario of Slow Onset Disaster-SLOD may impact the reaction of outdoor environment users exposed to a Sudden Onset Disaster-SUOD by inducing specific usage behaviours before evacuation. This evaluation is conducted by examining both static and dynamic indicators, along with associated metrics established in D422, D423, and D424, which aim to assess the current and post-retrofit level of risk.

2. Methods:

Following the methodology and related tools described in WP4, the risk assessment of SLOD, air pollution and heat wave events is based on the dynamic analysis of the Air Quality Index (AQI) and the Universal Thermal Climate Index (UTCI) of the current square configuration to derive Key Performance Indicators (KPIs) and risk metrics, respectively, for the pre-mitigation state. Meanwhile, for the risk analysis, SUOD developed a system of indicators to assess the exposure conditions and vulnerability of users, as well as the physical, geometric and morphological characteristics that influence possible risk scenarios.

Firstly, the KPIs developed in D4.2.2 and D4.2.3 are defined and then combined with the metrics (D4.2.4) to provide a single indicator for SLOD and SUOD risk (as only one rapid onset risk is considered possible for each of the case studies). Ultimately, the two metrics are also combined into a single multidimensional vector representing the multiple risk of the site. Complete analyses were carried out only for the cases of Piazza dell'Odegitria and Piazza dei Priori; from the investigations carried out, Piazza Vittorio Emanuele II was found to be an unrepresentative case from a multi-risk perspective. Only the SLOD analyses and the static KPI analysis for the SUODs are reported in order to provide an overall picture of the case study.

In view of the above, the analysis (and thus the results) are structured according to the SLOD-to-SUOD methodology, and by replicating the pre-retrofit rationale as applied for the BETs in D4.2.4, that is by providing:

1) The short overview of the case study features
2) The SLOD-related simulation results using the simulation tools defined in D.4.1.1 and to D4.2.3 KPIs and D4.2.4 metrics

3) The SUOD-related simulation results using the simulation tools defined in D.4.1.1. In this step, the KPIs assessment according to D4.2.2 is provided. Additional analysis are focused on the comparison of the evacuation response without and with heatwaves conditions (Quagliarini et al. 2023)
4) The Final metrics and multi-risk vectors assessment according to D4.2.4

Comparisons with the BETs are provided in the process, thus stressing possible differences between ideal and real conditions.

3. Results and discussion

The proposed method of analysis based on the use of the methods, respectively described in D4.2.2 for SUODs and in D4.2.3 for SLODs was further validated through application to three real case studies:

- Piazza dell'Odegitria (Bari, BA);
- Piazza dei Priori (Narni, TR);
- Piazza Vittorio Emanuele II (Caldarola, MC).

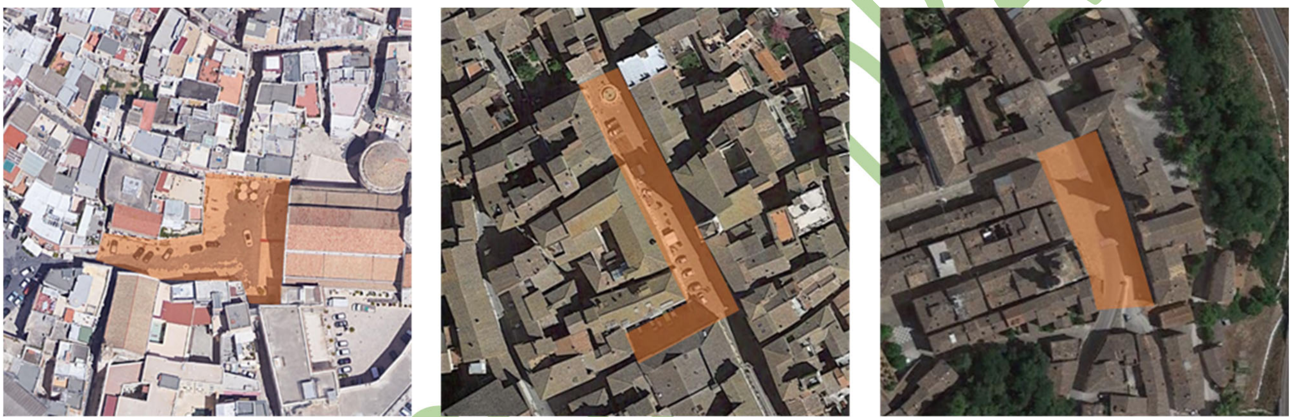


Figure 1. Selected case studies. From the left: Piazza dell'Odegitria (Bari, BA); Piazza dei Priori (Narni, TR); Piazza Vittorio Emanuele II (Caldarola, MC)

These case studies were chosen, from a selection of Italian squares, according to the similarity with the BET definition (D321; D'Amico et al. 2021; Rosso et al. 2022) and the SLOD and SUOD multi-hazard potential associated.

As outlined in D321 and summarised in D424, BETs vary in their susceptibility to hazards based on their morphology, geometry, and function. BET 4B, in particular, exhibits higher sensitivity to air pollution risks for SLODs and SUOD risks, including earthquake and terrorist attacks. BET 2A exhibits a greater susceptibility compared to the other BETs to all usual SLOD risks, such as air pollution and the heat island effect, which is linked to the occurrence of heat waves, as well as SUOD risks, such as earthquakes and terrorist attacks. On the other hand, BET 1A is particularly vulnerable to all SLOD and SUOD risks, with the exception of seismic risk.

Subsequent analysis of the related case studies will reveal differences. The evidence obtained through spatial, urban, and in situ context analyses enables determination of the primary hazards to which the square is exposed. Pertaining to Piazza dell'Odegitria, concerning the SLODs, the risk associated with heatwaves is noteworthy in the area, taking into account the city's climatic situation in the Mediterranean region. The potential risk of air pollution cannot be ruled out due to the square's location in a non-pedestrian urban area, where vehicular traffic could be present.

As for SUODs, the primary concern is the risk of terrorism. The seismic risk is low, as indicated by the seismic zoning, which places Bari in Class 3. Therefore, the risk has not been taken into account in this discussion.
Given this overall picture, there is a difference between the multi-hazard scenarios prevalent in the square under consideration, namely Heatwave, Terrorism and Pollution risk, and those to which BET 4B is prone, namely Pollution, Terrorism, and Seismic risk.
The case study of Piazza dei Priori is essentially characterised only by Pollution, Heatwave and Seismic risk, suggesting a typological differentiation, as expected.
Piazza Vittorio Emanuele, on the other hand, is characterised by Heatwave and Seismic risk, again outlining a differentiation from the associated BET.

Finally, for each proposed BET three different space configurations have been analysed (D422), with the goal of representing as many real-world scenarios as possible. In fact, each of the three case studies was associated with a BET and a specific geometric configuration. In particular, Piazza dell'Odegitria, due to its small size and the presence of two churches is associated with BET 4B, configuration C1 in that there are no monuments in the centre of the space but only a series of dehors on the sides of the square, defined by bollards or planters; Piazza dei Priori is associated with BET 2A, in configuration C3, with bollards with chains and monument given the presence of numerous planters to delimit the areas of the square and the fountain on the north side; finally, Piazza Vittorio Emanuele II is represented by BET 1A, configuration C1 in that it is presented as a square with a fairly steep slope (up to 26%) and with the provincial road, bordered by bollards with chains, running through it.

3.1 SLODs simulations on selected case studies

Following the methodology and related tools described in D411, the risk assessment of SLOD, air pollution, and heatwave events is based on the dynamic Air Quality Index (AQI) and Universal Thermal Climate Index (UTCI) analysis of the current square configuration. This allows us to derive Key Performance Indicators (KPIs) and risk metrics for the D423 pre-mitigation condition. Technical term abbreviations are explained when first used to ensure comprehension. The language used throughout is clear, objective, and simple.

The results for the case studies are given below.

Piazza dell'Odegitria, Bari (BA)

Figure 2 shows, for the case of air pollution, the comparison between the distribution maps of the AQI of Piazza dell'Odegitria and the reference BET 4B, both calculated by applying the boundary conditions characteristic of Bari, and the relative KPIs obtained by summing the risk of hospitalisation and the risk of mortality.

	Piazza dell'Odegitria	BET 4B
Transient behaviour	Short term risk = 0,25	Short term risk = 2,18
Long permanence	Short term risk = 0,17	Short term risk = 1,68

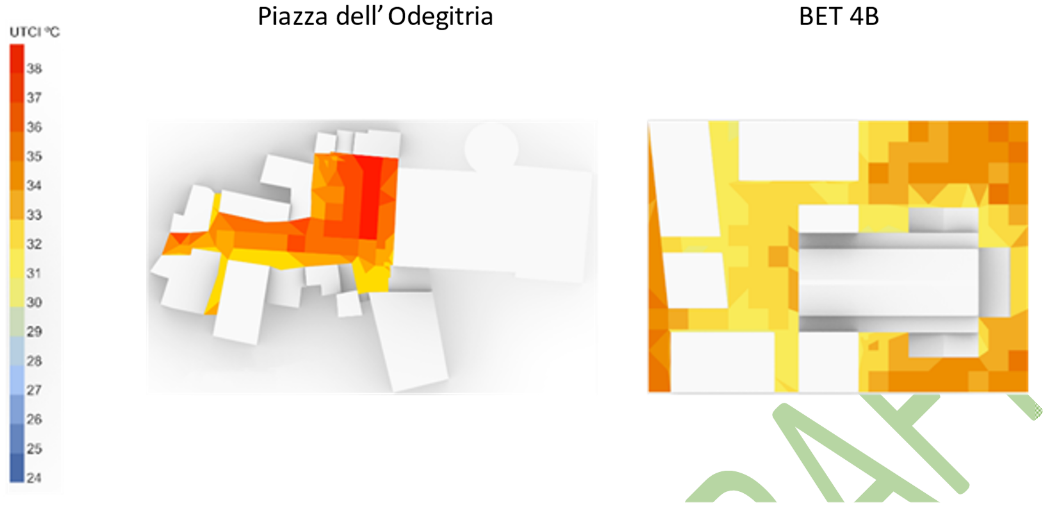
Figure 2. Comparison of air pollution risk conditions in the pre-mitigation scenario of Piazza dell'Odegitria and reference BET 4B.

The maps in Figure 2 (in chromatic scale) show that the maximum KPI in Piazza dell'Odegitria is about 6 points lower than in the reference BET, with the highest values concentrated in the part of the square with the road. As a result, the KPI values of Piazza dell'Odegitria also result in lower values compared to BET 4B. Therefore, the risk associated with pollution for the case study was deemed negligible, unlike in the reference BET (see D423).

Figure 3 illustrates the distribution maps of Piazza dell'Odegitria's UTCI and the reference BET in the pre-mitigation scenario. It establishes the relative KPIs by calculating the unweighted sum of the water loss for each user class (WLR_{age}).

Contrary to what was verified for pollution, the maps in Figure 3 (colour scale) show that the maximum value of the UTCI in Piazza dell'Odegitria is higher than that of the reference BET by about 5°C, with a consequent increase in the KPI values in the case study. In particular, the maximum value of the UTCI is recorded in the part of the square facing the Cathedral, close to the dehor area of the bar (value around 38°C). The value of the KPI is reduced in cases where users spend a long time in the open space, given the more restrictive level of acceptability of the same at a behavioural level, compared to the higher UTCI values.

	Piazza dell' Odegitria	BET 4B



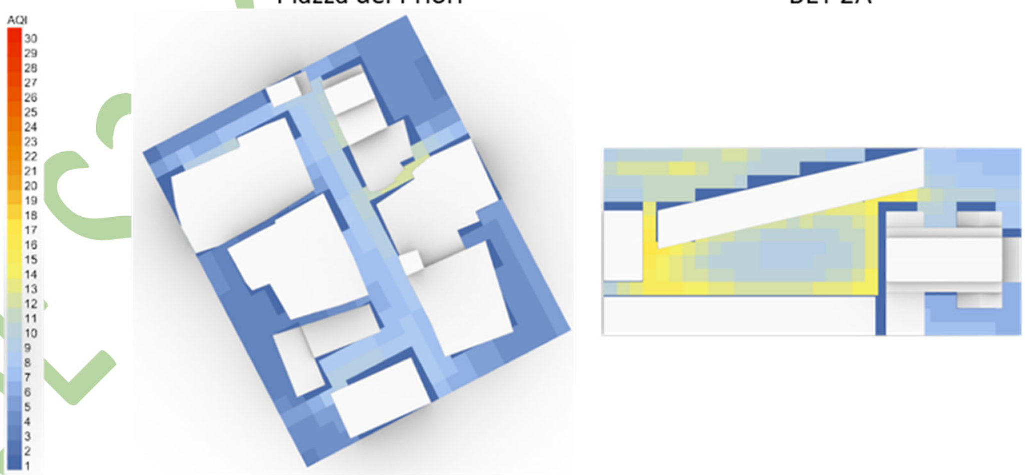
Transient behaviour	WLR_{age} = 4,18	WLR_{age} = 3,46
Long permanence	WLR_{age} = 3,37	WLR_{age} = 2,71

Figure 3. Comparison of heatwave risk conditions in the pre-mitigation scenario of Piazza dell'Odegitria and reference BET 4B.

Piazza dei Priori, Narni (TR)

As for air pollution, Figure 4 presents a comparison between the AQI distribution maps of the Piazza dei Priori case and the reference map of BET 2A. Both were calculated using the boundary conditions typical of Narni, alongside the related KPIs; the summed risk of hospitalization and mortality.

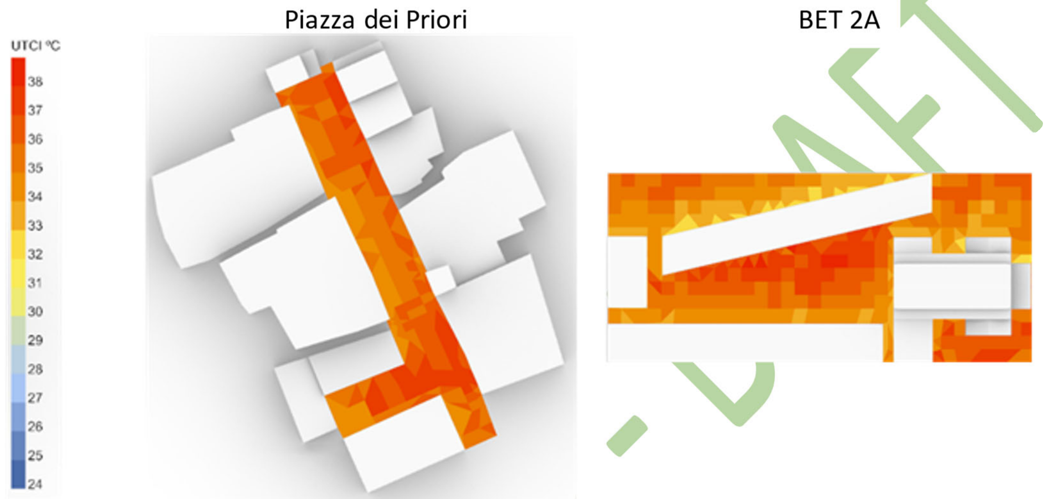
	Piazza dei Priori	BET 2A



Transient behaviour	Short term risk = 0,17	Short term risk = 0,84
Long permanence	Short term risk = 0,08	Short term risk = 0,59

Figure 4. Comparison of air pollution risk conditions in the pre-mitigation scenario of Piazza dei Priori and reference BET 2A.

As illustrated by the maps in Figure 4 (colour scale), the AQI within Piazza dei Priori consistently stays below 13, whereas in BET 2A, it reaches a value of 17 in the streets within the square. This indicates that the KPI values of Piazza dei Priori are comparatively lower than those of BET 2A, but there is a similar downward trend in KPI values with an increase in the time users spend in the open space. This finding suggests that the potential risk presented by Piazza dei Priori is minimal, in comparison to BET 2A. The analysis for heatwave involved carrying out a similar comparison process. This was achieved by utilizing distribution maps of the UTCI, which illustrated the relevant KPIs as the total of each user class's WLR_{age} (see Figure 5).



	Piazza dei Priori	BET 2A
Transient behaviour	WLR_{age} = 5,36	WLR_{age} = 5,31
Long permanence	WLR_{age} = 3,58	WLR_{age} = 3,54

Figure 5. Comparison of heatwave risk conditions in the pre-mitigation scenario of Piazza dei Priori and reference BET 2A.

As illustrated by the maps in Figure 5 (with colour scale), the UTCI distribution in the two scenarios is highly comparable, with mean values of approximately 35°C. As a result, there exists only minor disparity in KPI values for both temporary and permanent conditions.

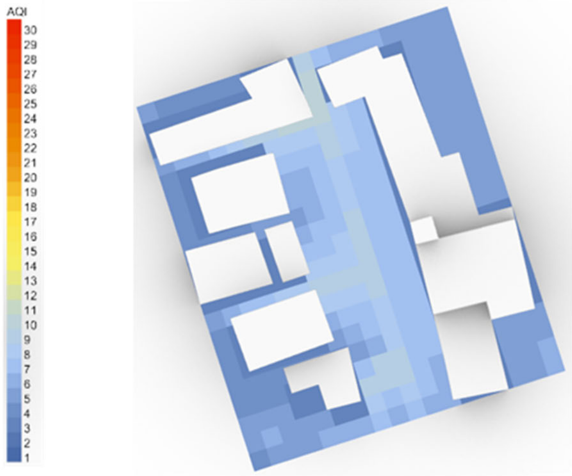
Piazza Vittorio Emanuele II, Caldarola (MC)

Figure 6 presents the AQI distribution maps for air pollution in Piazza Vittorio Emanuele II, the reference map of BET 1A is not available for this case. This is calculated using the boundary conditions typical of Caldarola, alongside the related KPIs; the summed risk of hospitalization and mortality.
The maps in Figure 6 (in chromatic scale) show that the AQI within Piazza dei Priori consistently stays below 11. As a result, the KPI values of Piazza Vittorio Emanuele are very low. Therefore, the risk associated with pollution for the case study was deemed negligible.

Figure 7 illustrates the distribution maps of Piazza dei Priori's UTCI and the reference BET in the pre-mitigation scenario. It establishes the relative KPIs by calculating the unweighted sum of the water loss for each user class (WLR_{age}).
The maps in Figure 7 (colour scale) show that the maximum value of the UTCI in Piazza dell'Odegitria is higher than that of the reference BET, with a consequent increase in the KPI values in the case study. In particular, the maximum value of the UTCI is recorded in the part of the square facing the Cathedral, close

to the dehor area of the bar (value around 38°C). The value of the KPI is reduced in cases where users spend a long time in the open space, given the more restrictive level of acceptability of the same at a behavioural level, compared to the higher UTCI values.

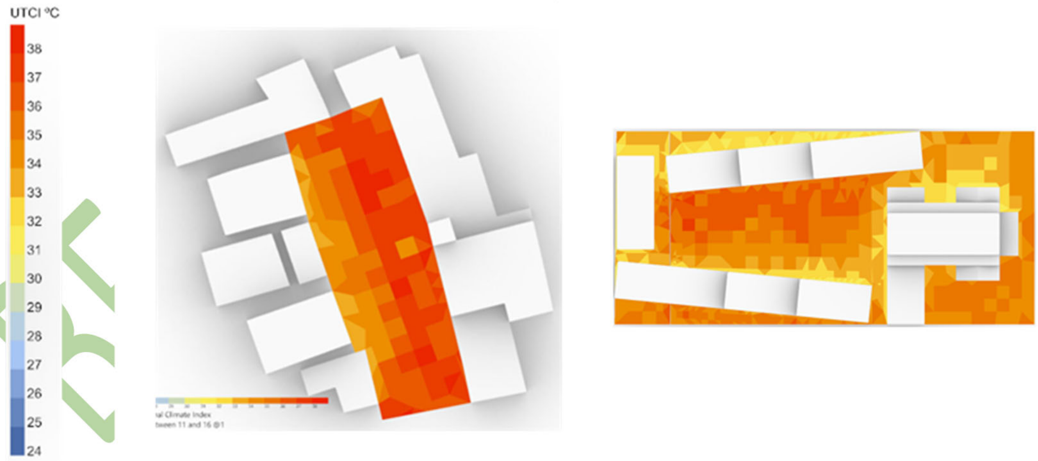
	Piazza Vittorio Emanuele II	BET 1A



Transient behaviour	Short term risk = 0,25	-
Long permanence	Short term risk = 0,17	-

Figure 6. Comparison of air pollution risk conditions in the pre-mitigation scenario of Piazza Vittorio Emanuele II and reference BET 1A (for air pollution risk the AQI analyses for BET are not available)

	Piazza Vittorio Emanuele II	BET 1A

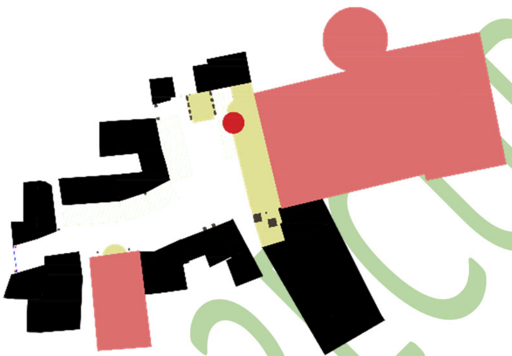


Transient behaviour	WLR_{age} = 5,54	WLR_{age} = 4,86
Long permanence	WLR_{age} = 3,58	WLR_{age} = 3,42

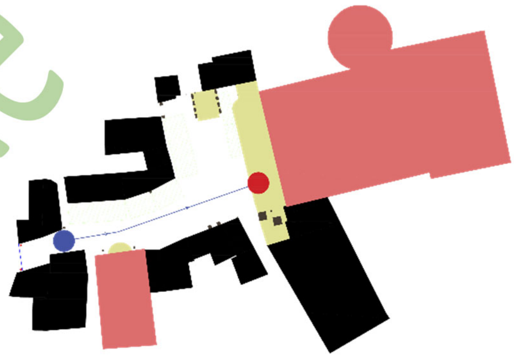
Figure 7. Comparison of heatwave risk conditions in the pre-mitigation scenario of Piazza Vittorio Emanuele II and reference BET 1A.

3.2 SUODs simulations on selected case studies

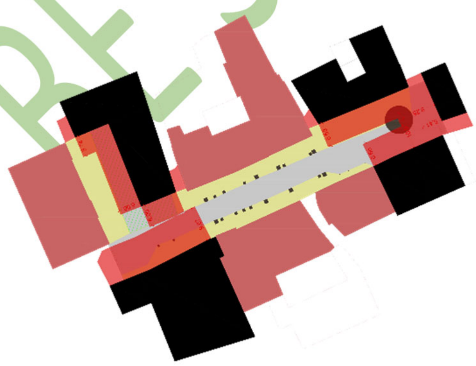
About SUODs risk scenarios, similarly to what was done for BETs (D422), the base scenario (Sb) which for the earthquake means the normal situation in an earthquake-prone area and for terrorism to the false alarm, the earthquake risk scenarios (SE1 and SE2) and terrorist risk scenarios (ST1 and ST2) were examined. For the assessment of the risk of a terrorist attack at Piazza dell'Odegitria, all potential modes of attack targeting the crowd congregated in front of the Special Building (i.e. the church) were taken into account. Such scenarios include an assault with a hand weapon (ST1) or a vehicle driven into the crowd (ST2) coming from the entrance to Piazza Federico II, as shown in the maps A and B in Figure 8. For the seismic risk analysis of Piazza dei Priori, damage scenarios are evaluated based on TR=475 for the first case (SE1) and TR=975 for the second case (SE2). The estimated debris resulting from seismic events of this intensity is graphically illustrated in Figure 8.C and Figure 8.D. The damage scenarios for Piazza Vittorio Emanuele II, as illustrated in Figure 8.E and Figure 8.F, are subject to the same assessment.
The selection also considered the feasibility or availability of laser scanning surveys, exposure data, and climatic data. The three squares were fully surveyed and digitally reproduced using a meso-scale BIM model designed to be an effective repository of information for single and multi-risk assessments (D332). Each geometrical element of the model was used to implement the related risk parameters identified as key multi-risk factors (D332; Angelosanti et al. 2022).



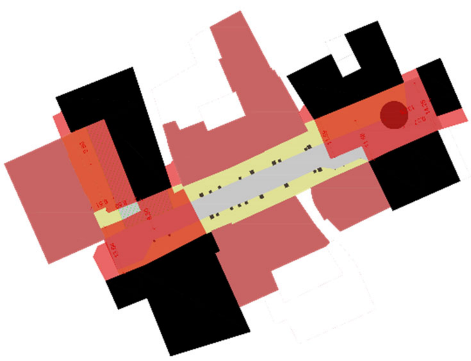
A _ Piazza dell’Odegitria, Bari (BA)_ST1



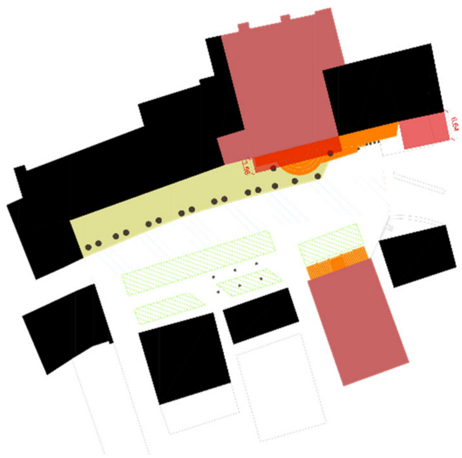
B _ Piazza dell’Odegitria, Bari (BA)_ST2



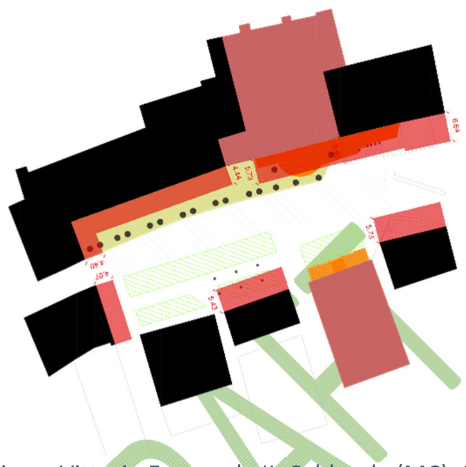
C _ Piazza dei Priori, Narni_SE1



D _ Piazza dei Priori, Narni_SE2



E _ Piazza Vittorio Emanuele II, Caldarola (MC)_SE1



F _ Piazza Vittorio Emanuele II, Caldarola (MC)_SE2

Figure 8. Summary representation of risk scenarios for each case study

The application of KPIs to real case studies confirmed the effectiveness of the proposed method of analysis and the comparison with the associated BETs shows a general similarity in the KPI results. The main differences are found in the use of local crowding and density data for each case study.
The density coefficient used for the calculation of the KPIs for BETs was selected from the median values of UDC (Users' Daily Characterisation) estimated through the analysis of a sample of 56 Italian squares and described in (Quagliarini et al. 2023b). To better represent reality, the median value of UOod (Users' overall outdoor density) for working days of 0.22 pp/m^2 was used. The Users' overall outdoor density in relation to the UDC, considers both outdoor and indoor users out of the buildings, thus considering all the users contemporarily in outdoor areas, such as in evacuation conditions. Considering the median data, working days and holidays appear to be characterized by the same levels of density in outdoor. However, in peak conditions, the difference between working days and holidays appears to be significant and working days present more critical conditions than holidays. This implies a slight impact of users outdoor on the overall conditions when circumstances can force them to move inside the buildings searching for safety or shelter (e.g., in case of terroristic attack outdoors; unacceptable environmental outdoor conditions related to air pollution or heatwaves).

3.2.1 Users' exposure, vulnerability and behaviours: input data for simulations

The case study overview in terms of exposure and users' vulnerability is reported in D3.3.3. In this section we will explore the main elements affecting simulations in the SLOD-to-SUOD perspective. In particular, simulations have been performed for Piazza dell'Odegitria (Bari) and for Piazza dei Priori (Narni), thus allowing to respectively consider effects of terrorist acts and earthquakes on the users and their behaviours and, at the same time, to respectively simulate a BE direct connected to a BET (i.e. BET4B) and a BE which represents an extension of the BETs (in view of its morphology, i.e. concave shape) but can be also ideally associated with the BET 2A.

Piazza dell'Odegitria and Piazza Vittorio Emanuele II are very similar to the associated BETs. In both cases only two buildings are classified as special buildings and they are two churches. Several commercial activities are present, but the density values remain in line with the median values for the BET, and they are respectively 0.21 pp/m^2 for Piazza dell'Odegitria and 0.26 pp/m^2 for Piazza Vittorio Emanuele II. Nevertheless, Piazza dell'Odegitria (Figure 9) has a wide variability during the holidays, with the overall median value that is close to the BET one (0.21 pp/m^2) but differences in the special building (chiesa-church) density (0.7 rather than 0.4 pp/m^2 as in the BET generic public building), while the maximum (peak) value is higher than 1. Nevertheless, the 0.21 and the >1pp/m^2 scenarios essentially consider a similar number of only outdoors and prevalent outdoor users, since the 85% of the population is initially placed indoors (see the right panel of Figure 9), apart from the users waiting for entering the church. These people are not directly exposed to terrorist acts, thus they are not simulated, being placed indoors. Thus variations between these two conditions are limited.

In Piazza dei Priori (Figure 10), the presence of four different Special Buildings (a church, a theatre, a university, the town hall) and numerous commercial activities such as bars, restaurants and shops resulted in a median density value of 0.43 pp/m^2, while the minimum density is similar to the median values of the BETs (0.22 pp/m^2).

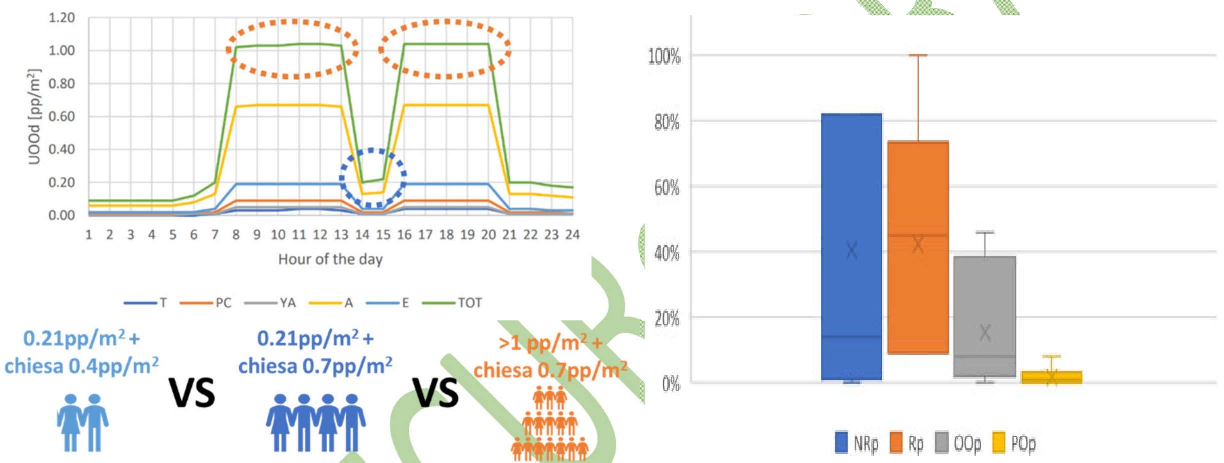


Figure 9. Density of users (by typologies) over time for piazza dell'Odegitria (Bari) and the three preliminary considered simulation scenarios (with icons used in the following graphs). On the right, the percentage distribution (boxplot) for non residents (NR), residents (R), only outdoor (OO) and prevalent outdoor (PO) users.

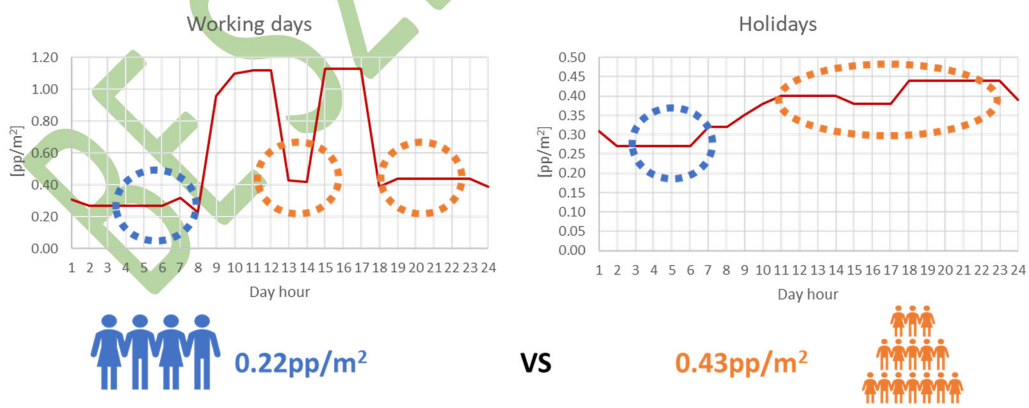


Figure 10. Density of users (by typologies) over time for piazza dei priori (Narni) and the two preliminary considered simulation scenarios (with icons used in the following graphs).

Beside the users' density in Figure 9 and Figure 10, Typical behaviours are considered as in D4.1.1 outcomes (i.e. See Section 4 and 5), according to the simulation rules in the developed agent-based model. The same behavioural values are adopted:

1) For each heatwave scenario (basic UTCI and no UTCI for Bari; basic UTCI, no UTCI and UTCI 1 hour for Narni) (Quagliarini et al. 2023);
2) For each SUOD condition (Sb=generic/false alarm, ST1=weapon and ST2=vehicle attack for Bari; Sb=no debris, SE1=debris for TR=475 years and SE2=debris for TR=975 years for Narni[1]);
3) just in the Narni case study, for the general assessment conditions (called "generic"), in which the users' distribution in buildings I homogeneous (like for the BETs) and for the specific assessment conditions /called "updated users' position"), in which the users' position in buildings depends on the effective maximum number of occupants, thanks to in situ surveys. In this second scenario, the building exits are retrieved too.

Table 1 and Table 2 finally traces additional data for earthquake simulations for the case study of Narni, according to the main parameters and their variability range as assumed in D4.1.1, Section 4. All the values are repeated for all simulations carried out except for the value of no collapsed which varies depending on whether the debris is present or absent.

Table 1. Input scenario definition: specific inputs for the Narni Case study about buildings

	KPI	Unità di minura	All scenarios
OTHER INPUTS	Evacuationmode	[-]	entering
	Bucperc	[%]	20
	Maxsimtime	[s]	600

Table 1 introduces the evacuation modes and the maximum time set in the simulator to observe the evacuation. All values are the same for each simulation carried out.

Table 2. Input scenario definition: specific inputs for the Narni Case study about earthquake effects on the users

	KPI	Unità di minura	All scenarios	
EARTHQUAKE	TSAP	[%]	88	
			no debris	debris 475 and 975
	Noncollapsed	[%]	100	83
	Seismicdisfin	[patches]	1	
	Seismicrandompatch	[patches]	500	

3.2.2 KPIs overview

Table 3 resumes the KPIs values for the assessed case study. Tor Caldarola, no evacuation simulations have been performed. Thus the analysis of these conditions have been performed only with "static" KPIs as described in D4.2.2. In the meanwhile, Table 4 offers the comparison with the related BETs KPIs, which are fully provided according to the performed simulation (compare with D4.2.2 and D4.2.4).

[1] The same return time TR have been considered also for Caldarola, but no evacuation simulations have been performed. Thus the analysis of these conditions have been performed only with "static" KPIs as described in D4.2.2.

Table 3. KPI values for case studies, in three risk configurations: Sb - SE1 - SE2 for Piazza dei Priori ("generic" simulations on users' position at the starting of the process) and Piazza Vittorio Emanuele; Sb - ST1 - ST2 for Piazza dell'Odegitria.

Case studies	Piazza dell'Odegitria (Bari, BA)			Piazza dei Priori (Narni, TR)			Piazza Vittorio Emanuele II (Caldarola, MC)		
	Sb	ST1	ST2	Sb	SE1	SE2	Sb	SE1	SE2
KPI 1	-	-	-	0.00	0.51	0.00	0.00	0.04	0.24
KPI 2	0.33	0.33	0.33	0.26	0.89	0.22	0.22	0.22	0.69
KPI 3	0.14	0.14	0.14	0.34	0.34	0.31	0.31	0.31	0.31
KPI 4	0.48	0.48	0.48	0.12	0.65	0.07	0.07	0.17	0.69
KPI 5	0.90	1.00	0.95	0.87	0.98	0.75	0.75	0.76	0.83
KPI 6	0.00	0.82	0.82	0.00	0.54	0.69	0.00	0.51	0.75
KPI 7	0.10	0.11	0.10	0.37	0.18	0.19	-	-	-
KPI 8	0.58	0.55	0.44	0.10	0.21	0.19	-	-	-
KPI 9	0.28	0.37	0.43	0.87	0.77	0.79	-	-	-
KPI 10	0.00	0.08	0.22	0.01	0.04	0.04	-	-	-
KPI 11	0.00	0.18	0.49	-	-	-	-	-	-
KPI 12	0.00	0.96	0.49	-	-	-	-	-	-

Table 4. Summary of KPI values for the BETs associated with the case studies (in grey, KPIs related to simulation which are not considered in the case study application, see above).

BETs	4B configuration C1			2A configuration C3			1A configuration C1		
	Sb	ST1	ST2	Sb	SE1	SE2	Sb	SE1	SE2
KPI 1	-	-	-	0.00	0.04	0.53	0.00	0.05	0.43
KPI 2	0.18	0.18	0.18	0.19	0.60	1.00	0.17	0.58	1.00
KPI 3	0.33	0.33	0.33	0.34	0.34	0.34	0.40	0.40	0.40
KPI 4	0.25	0.27	0.27	0.29	0.36	0.95	0.32	0.38	0.81
KPI 5	0.78	1.00	0.90	0.42	0.45	0.78	0.33	0.37	0.66
KPI 6	0.00	0.71	0.71	0.00	0.50	0.93	0.00	0.55	0.91
KPI 7	0.05	0.06	0.06	0.26	0.36	0.48	0.32	0.48	0.81
KPI 8	0.24	0.58	0.27	0.05	0.07	0.06	0.04	0.03	0.01
KPI 9	0.39	0.49	0.63	0.82	0.87	0.90	0.82	0.88	0.93
KPI 10	0.00	0.10	0.22	0.01	0.00	0.01	0.01	0.02	0.07
KPI 11	0.00	0.14	0.46	-	-	-	-	-	-
KPI 12	0.00	1.00	0.50	-	-	-	-	-	-

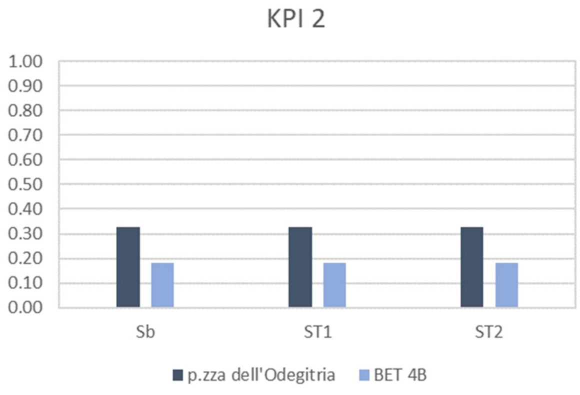
The graphs in Figure 11 summarize the risk of terrorism for Piazza dell'Odegitria in **Bari** that has been selected to validate the KPIs related to terrorism. The analysis of the results shows good consistency with the KPI values calculated in the associated BET, both in numerical terms and in the general risk profile. The KPI with IDs 2, 3 and 4 are not influenced by the risk scenario, because the conditions are not changed. In fact, no generation of debris was assumed following a terrorist attack, so the streets remain free and available for escape (KPI 2 and 3), and the obstacles remain the same as for the baseline scenario (bollards, planters, dehors etc.) (KPI 4). KPIs 5 and 6 have progressively increasing values depending on the type of attack. The first, Temporary secure Open Spaces have all very high values. This result is to be found in the small size of the square, which is restrictive and unsafe due to the large number of users that can crowd the space, influenced especially by the presence of densely populated and particularly large Special Buildings. The KPI takes on even higher values in ST1 and ST2 scenarios, where the useful area is further reduced. In fact, the safe zones counted are those outside the attack trajectory or those behind an element that can act as a hiding place (monuments, large firerooms, etc.). KPI 6 (Figure 11.e) is perfectly aligned with the associated BET, in fact in the base scenario (which represents the risk-free condition and for terrorism represents the false alarm) the value is zero. In the ST1 and ST2 scenarios, the user exposure is very high, even higher than the BET. This condition is particularly representative of the real case given the presence of two churches, including the Cathedral of Bari (the metropolitan cathedral Basilica of San Sabino), an important attraction for tourists and the faithful.

The following dynamic KPIs are the result of a simulation process, as for BETs. KPIs 7 and 8 both describe the evacuation process, but as for BET, the values don't show the same trend, they are very low for the one and rather high for the other. The Evacuation time percentile (KPI 7 in Figure 11.f) is directly related to the time needed to reach a safe place and the small size of the square naturally contributes to minimizing this time, confirming the BET results. The Crowd effects (KPI 8 in Figure 11.g), on the other hand, measures the probability of physical contact during the evacuation process and registers very high values, as a great number of people are forced into a rather small space. The results are influenced by higher square complexity and density for the case study, especially in the generic condition (where there is no complication in interacting with attackers), while in the white-knuckle attack condition the results are close to the upper limit of 12%.

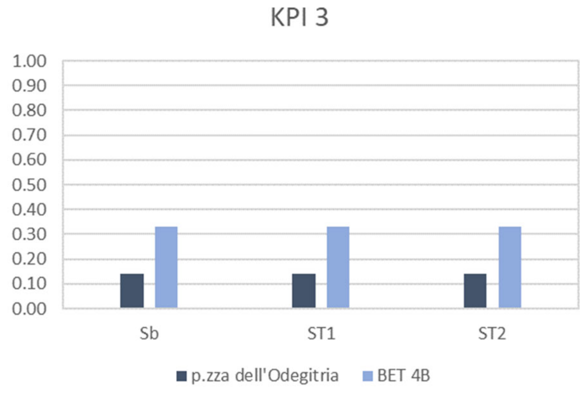
Similarly to what was observed for KPI 7, for Mean flow rate (KPI 9), the small size of the square also results in medium to low values, as users are able to more easily reach the exits and get to safety. KPI 10 quantifies the number of users who participate in the evacuation process. The number of evacuees arriving at the safe zone differs significantly for the knife attack, despite a relatively low absolute value. These differences highlight that the real-life case study is safer than the idealised one since it allows for more people to reach safety. The Number of deaths/casualties is calculated only for terrorism, and for Piazza dell'Odegitria is particularly high (especially for the vehicle attack ST1) given the large crowd of users in front of the target building, potentially involved in the terrorist attack.

As can be seen from the graphs in Figure 11 and in particular from the results of KPIs 9, 10, and 11 (Figure 11), which reflect a high fit between the case study and the associated BET, confirming the validity of the assessment method through KPIs.

The Obstacle protection rate (see value in Figure 11.k)used only for terrorism, confirms the trend and values of associated BET. In fact, there are no large obstacles in the square that can provide protection during a terrorist attack, only a series of bollards/posts delimiting pedestrian-only areas and streets, as well as the C1 geometric configuration (bollards with chains) selected for BET.


KPI 2
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Sb
ST1
ST2
p.zza dell'Odegitria
BET 4B

a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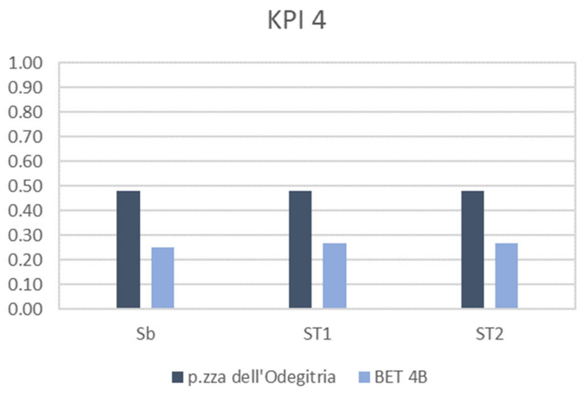
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Sb
ST1
ST2
p.zza dell'Odegitria
BET 4B

b


KPI 4
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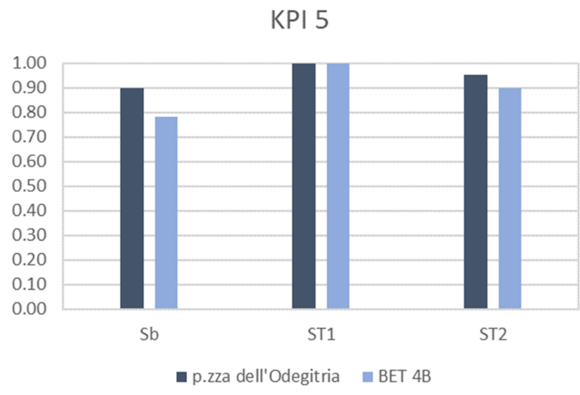
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Sb
ST1
ST2
p.zza dell'Odegitria
BET 4B

c


KPI 5
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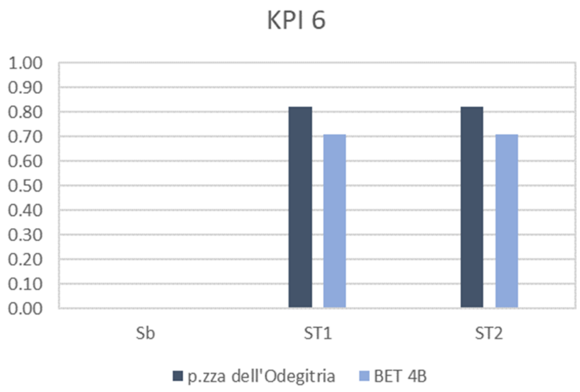
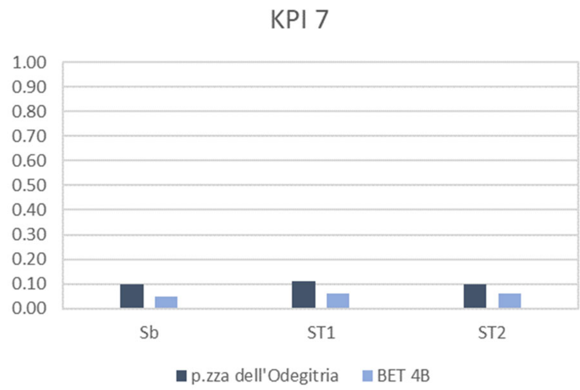
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Sb
ST1
ST2
p.zza dell'Odegitria
BET 4B

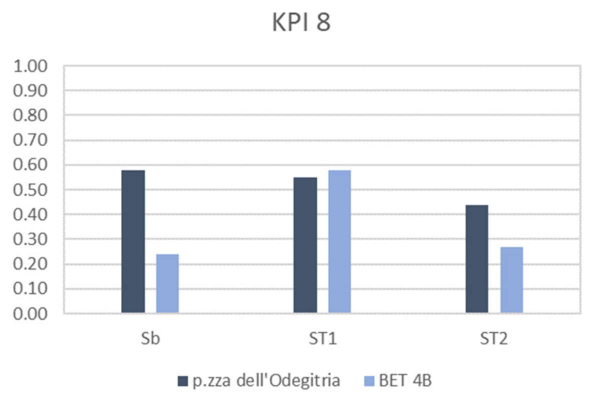
d


KPI 6
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Sb
ST1
ST2
p.zza dell'Odegitria
BET 4B

e


KPI 7
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Sb
ST1
ST2
p.zza dell'Odegitria
BET 4B

f



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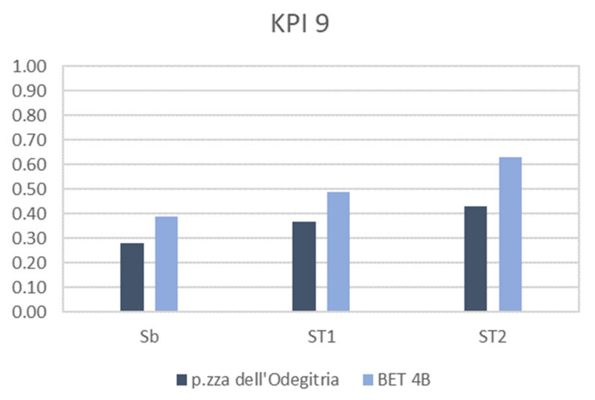

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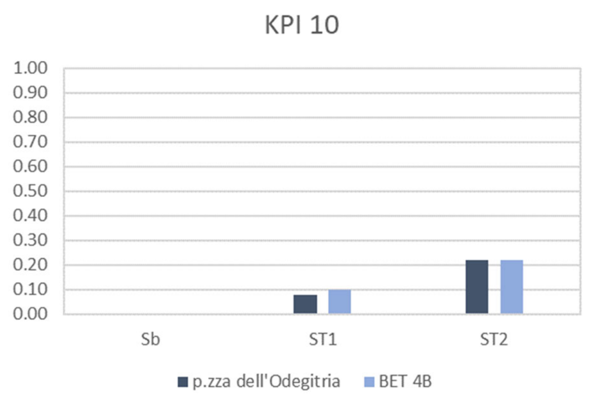
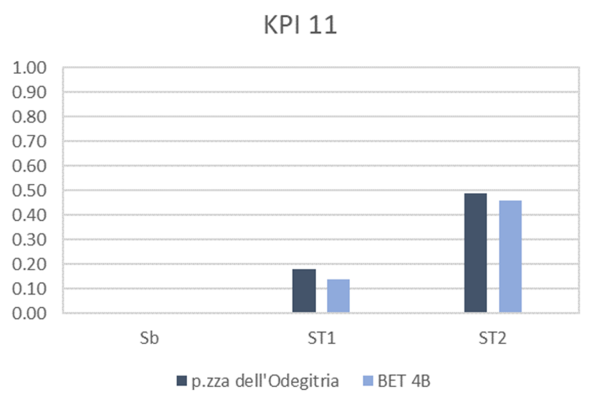


i



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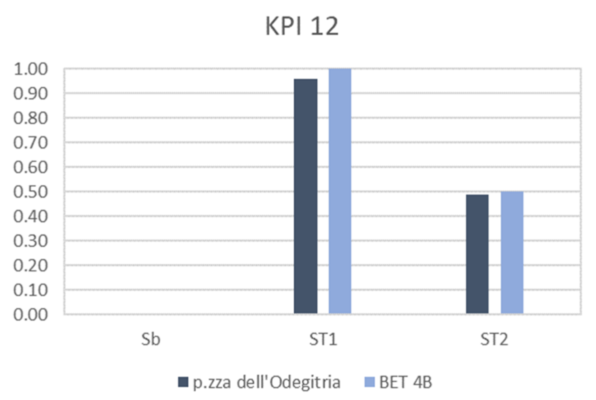
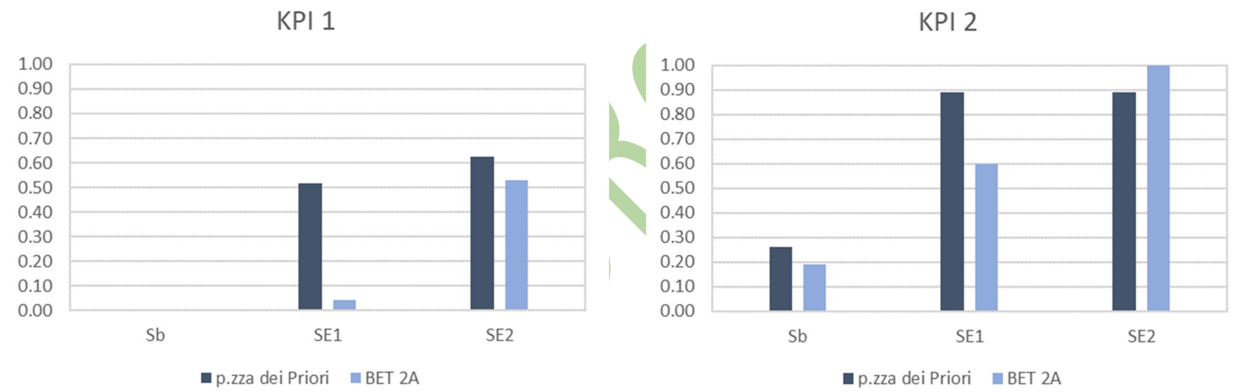


k

Figure 11. Summary graphs of KPI values in the three risk scenarios: comparison between piazza dell'Odegitria (Bari, BA) and BET 4B configuration C1

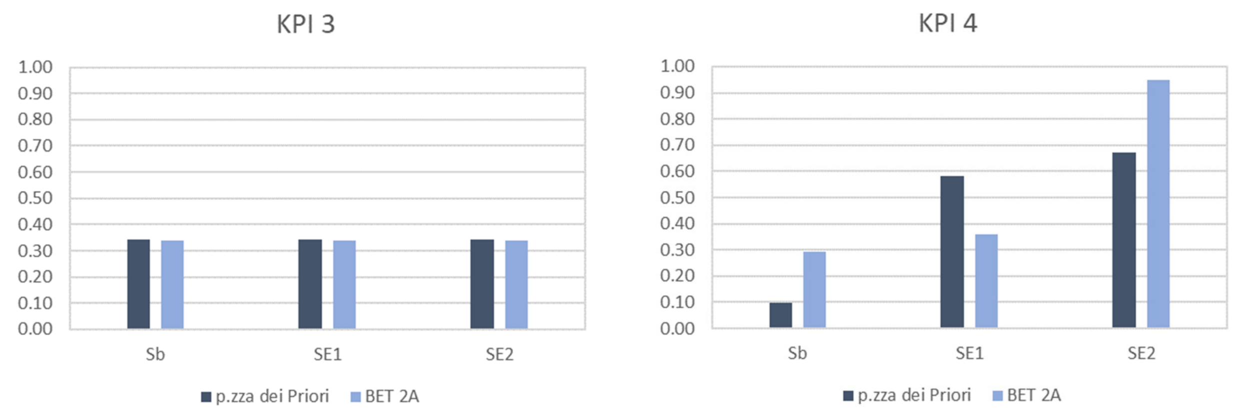
For seismic risk, the factor that most influences the results, leading to incongruences between BET and case study, is the potentially generated debris. In the case of **Narni**, already in the Earthquake Scenario 1 there is a lot of debris, especially damaging private buildings, on which it was not possible to find detailed information on masonry quality. For this reason and due to the reduced width of the square and access

roads, the KPI values for the case study are very high already from the first SE1 scenario, resulting in a different risk profile compared to the BET as can be seen in the graphs in Figure 12. The value of Balance index of debris (KPI 1) is very high compared to the associated BET for SE1 and are aligned with the BET strength coefficient for SE2. The road resistor coefficient (KPI 2) has the same value for SE1 and SE2 since all roads (except for one alley) are immediately blocked by debris. The obstacles (KPI 4) considered to be permanent in all scenarios for Piazza dei Priori are the planters placed to delimit the various areas of the square, the fountain and the dehors pertaining to the various shops. In the risk scenarios, the debris takes precedence over the common obstacles, completely covering the dehors in SE1 and involving the fountain in SE2. The safe area in Piazza dei Priori progressively decreases as the debris increases. In fact, the Temporary secure open space (Figure 12.e) has an increasing trend, with high values starting from the Basic Scenario due to the density of Special Buildings and accommodation activities that determine the presence of a high number of users. The profile of the Exposure index (Figure 12.f) has a worsening trend as the intensity of the seismic event increases as the number of users in open spaces potentially affected by debris increases.
Dynamic KPIs are also significantly influenced by the real circumstances described above.



a

b



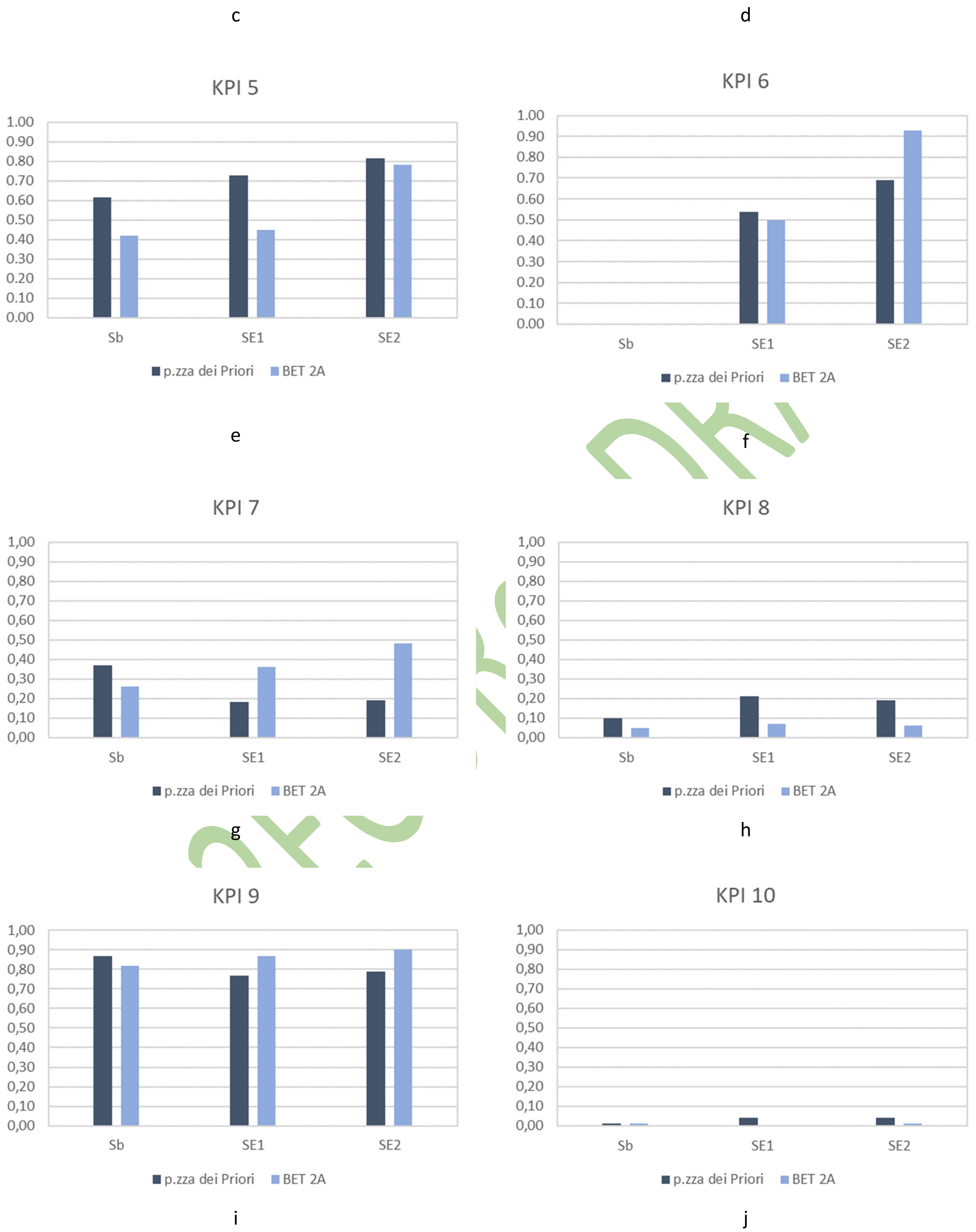
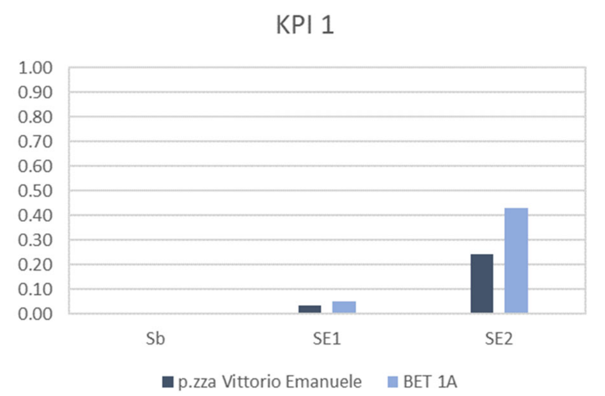


Figure 12. Summary graphs of KPI values in the three risk scenarios: comparison between piazza dei Priori (Narni, TR) and BET 2A configuration C3

For the case study of **Caldarola**, unlike the case of Narni, there is not a great generation of debris. In fact, also due to the size of the square, the safe areas remain large and accessible from the side streets that remain open; so the Temporary secure (Oss) (KPI 5), so the SOS takes on medium-low values in agreement with the associated BET, confirming the presence of a reasonably large safe open space. The Balance index of debris (KPI 1) is perfectly aligned with the results of the BET for SE1 and it is half smaller for SE2, due to the limited collapse of buildings (in the SE2 scenario for BET all buildings surrounding the square generate debris). The Road resistor coefficient (KPI 2) is equal for Sb and SE1 scenarios, as in the configuration with the 475-year return period, the debris is confined to the church on the east side of the square, which appears as a single closed front with no streets. In SE2 the R_{RC} value increases and only 2 of 7 roads remain fully open, severely limiting access to the square. The Obstacle friction rate (KPI 4) is rather restricted, since in analogy to the C1 configuration of BET, it depends exclusively on the presence of planters as point obstacles, to which debris is added in the SE1 and SE2 scenarios to the measure mentioned above. Finally, the Exposure index (KPI 6) follows an increasing profile, in agreement with the increased risk resulting from the scenarios presented although with slightly lower values than the associated BET, where the increase in debris is also more linear due to the assumptions made. Dynamic KPIs have not been included for Piazza Vittorio Emanuele II.



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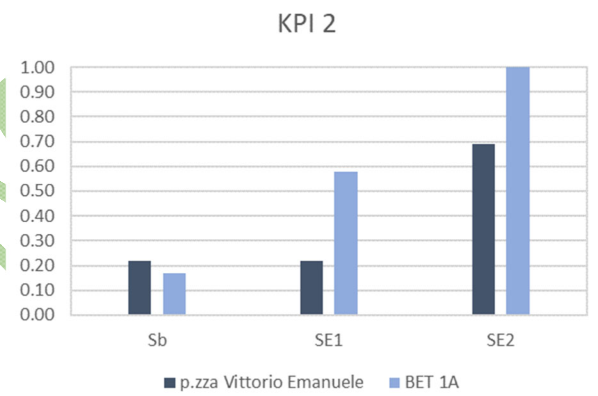

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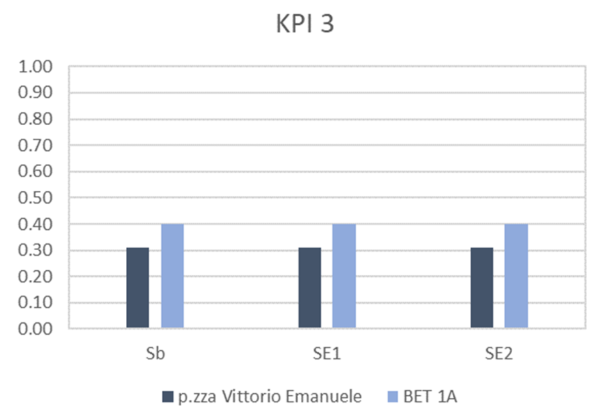

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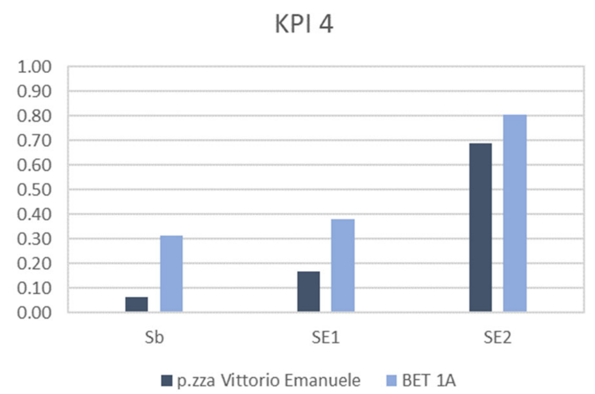

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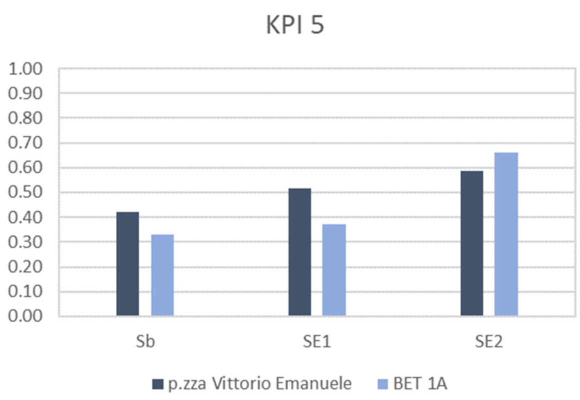

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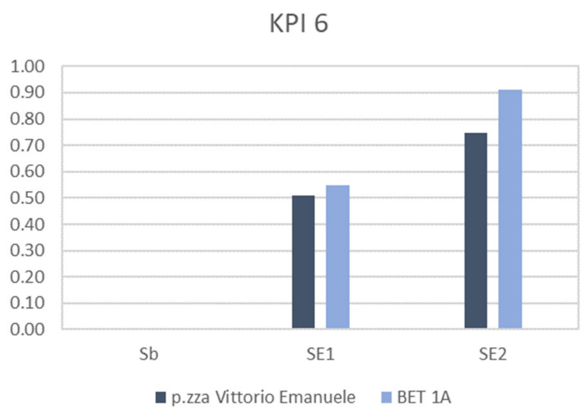

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Figure 13. Summary graphs of KPI values in the three risk scenarios: comparison between piazza Vittorio Emanuele II (Caldarola, MC) and BET 1A configuration C1

3.2.3 Evacuation process assessment and effects of users' distribution inputs on dynamics KPIs

In this subsection, effects of no UTCI, basic UTCI and 1-hour UTCI conditions as well as of the on the evacuation performance are investigated, since previous works of the project related to the BETs pointed out that they can contribute to the final impact of risks (Quagliarini et al. 2023). Similarly, for each case study, results of the evacuation process are detailed by commenting the evacuation curves in relevant conditions.

3.2.3.1 Analysis on Bari-related simulations

The analysis on the Bari-related simulations are focused on three main levels. The first one is aimed at comparing the impact of UTCI and no UTCI conditions on the evacuation process, and it is mainly performed by the analysis of the evacuation curve and by the analysis on behavioural KPIS. The median evacuation curves in no UTCI and UTCI scenarios depending on the attack conditions are shown in Figure 14. In general terms, the no UTCI scenarios generally lead to lower risk conditions, since the evacuation curves are more sloped than those in basic UTCI scenarios. As expected, moreover, false alarm is less risker than ST1 and ST2. The only exception is related to the weapon attack. In this case, the basic UTCI scenario is safer than the no UTCI ones, essentially since users are more scatter in basic UTCI conditions rather than in no UTCI ones, and thus direct effects of attackers are more limited.

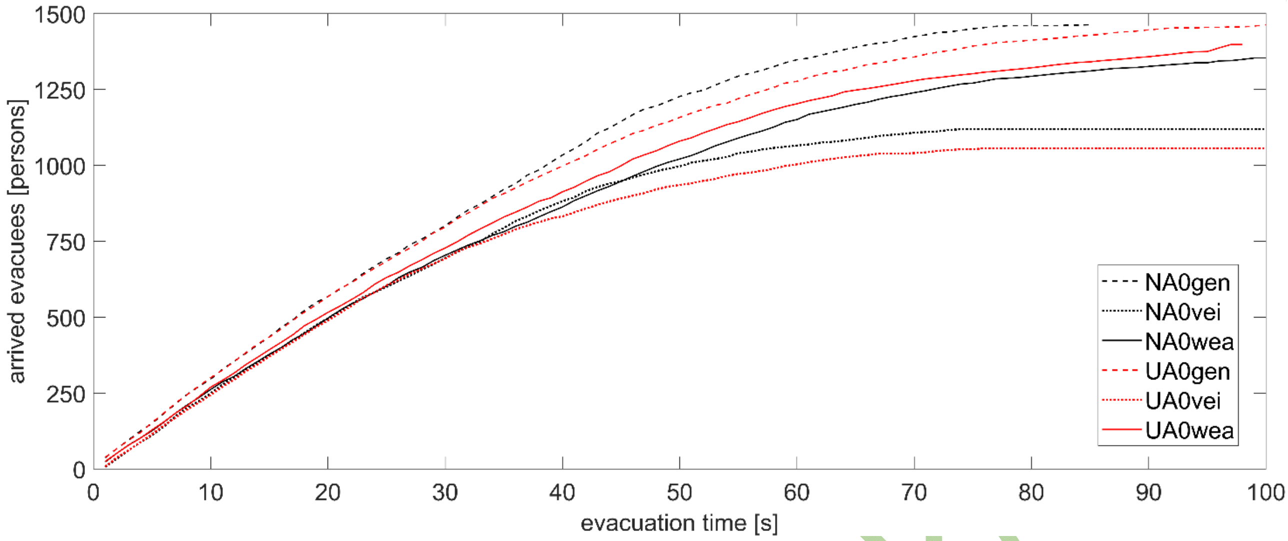

Figure 14. Median evacuation curves for no UTCI conditions (N) and basic UTCI (U) for the current scenario (A0) and considering SB false alarm (gen), ST1 weapons (wea) and ST2 vehicle (vei) attacks.

The second analysis concerns the users' density effects on the evacuation curve, as shown in Figure 15. The reported curves refer to the false alarm conditions so as to point out the main effects of users' interactions due to density maximization. As expected, highest the density, highest the evacuation time, but limited differences have been noticed between the >1pp/m^2 (dashed curve, with orange icon) and the 0.21pp/m^2 in case the density of users linked to the church is 0.7 pp/m^2 (continuous black curve, with dark blue icon). This fact is due to the presence of almost the same number of initial users, the vast majority of them related to the church visits. On the contrary, the 0.21 pp/m^2 with church density at 0.4pp/m^2 (as for the BET 4B) is the shortest one. In this case, the slope of the curve is lower in view of the lower density.

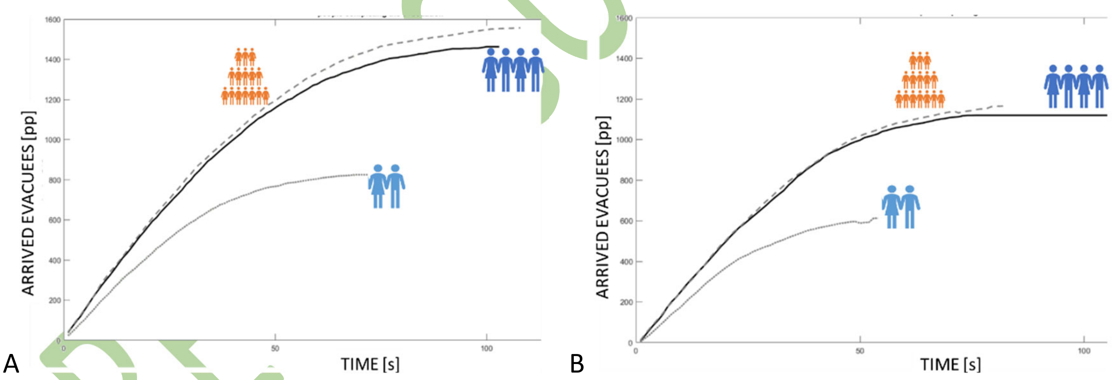

Figure 15. Median evacuation curves for the different users' density values, considering A=false alarm and B=vehicle attack. Icons are those of Figure 9.

The third analysis levels concerns the comparison between the case study and the BET 4B (reference BET) results in terms of KPIs, and it is shown in, considering the ST1 (weapons) in view of the prominent differences in trajectories in case of vehicle attack (ST2). Results and percentage differences of KPIs are shown in Table 5.

A general adherence is shown in terms of the effects of the attack in terms of casualties, i.e. dead and wounded (K11). The differences in the number of evacuators arrived at safe zone (K10) are significant for the knife attack although the absolute value is low, and show in particular that the case study seems safer than the idealized one since more people can get to safety: in fact, the percentage difference with the BET is negative. The KPI related to evacuation time (K7) varies depending on the density of people involved (in the case study, there are about two and a half times the number of people present in BET 4B); on the contrary, the flow condition (K9) remains constant in generic condition demonstrating that the speed of the process is similar, while in the condition of knife attack it decreases slightly by virtue of the lower value of K10. The amount of physical contact between people (K8) is influenced by greater complexity of the square and density for the case study, especially in the generic condition (where there is no additional effects due to the interaction with the attackers), while in the condition of knife attack the results are close in the upper limit of 12%.

Table 5. The "generic" simulations results (homogeneous users' position in the buildings at the starting of the process), depending on UTCI and damage scenarios.

	KPI				
	K7	K8	K9	K10	K11
generic – false alarm (SB)					
BET4B	0.052	0.242	0.385	0	0
Caso studio	0.124 (139%)	0.633 (162%)	0.375 (-2%)	0 (n.a.)	0 (n.a.)
weapon – SE1					
BET4B	0.057	0.511	0.491	0.1	0.14
Caso studio	0.122 (115%)	0.57 (12%)	0.411 (-16%)	0.05 (-50%)	0.134 (-3%)

3.2.3.2 Analysis on Narni-related simulations

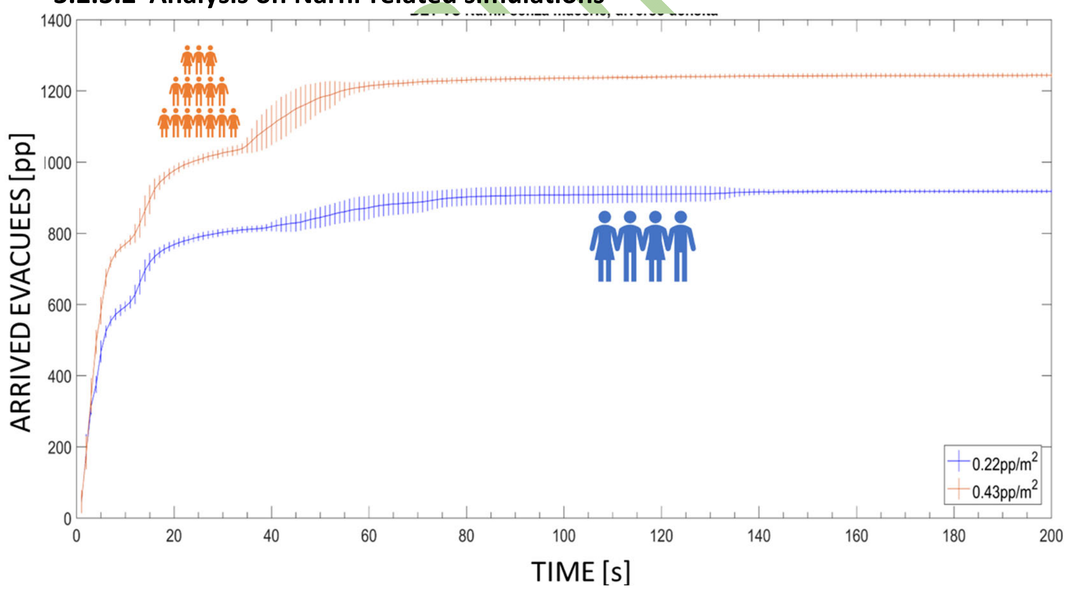

Figure 16. Evacuation curve for the Narni case study, Sb scenario, for the two main tested users' densities. Vertical bars shows the standard deviation as associated error to the mean evacuation curve.

Figure 16 traces the evacuation curve for the Sb scenario, in basic UTCI conditions, for the two densities adopted in the methodology. Both the curves are characterized by the same trends, suggesting that the evacuation process is divided into two main phases. The first one concerns the immediate arrival of the users hosted in the square and its buildings, which is characterized limited interferences which does not imply a significant deviation from the mean values (for 0.22 pp/m^2, up to 20s; for 0.43 pp/m^2, up to 40s). Then, the curves converge towards horizontal asymptotes, depending on the crowding levels. In this second phase, users involved in the process also come from the surrounding access streets, and they move in a more crowded environment within the square open space. When the crowding levels increase, perturbations in the users' evacuation curve trends are noticed: the standard deviation associated to the mean curve is higher because of the interactions between evacuees. Some users did not still stop their evacuation process, since they individually evaluate that the local conditions are not still safe from debris or have a high density of surrounding users.

The same trend is noticed in all the evacuation conditions, also in the presence of debris, as shown by Figure 17. Nevertheless, the number of users arriving in Sb is higher than the ones in SE1 and SE2, as expected, in view of SAP value and building damage/debris level outdoor. Moreover, the absence of debris increases the possible interaction between the users, and thus lead to different horizontal asymptotes over time. At the same time, it is worth noticing that the conditions for SE1 and SE2 are similar, in view of the similar debris and damage scenarios.

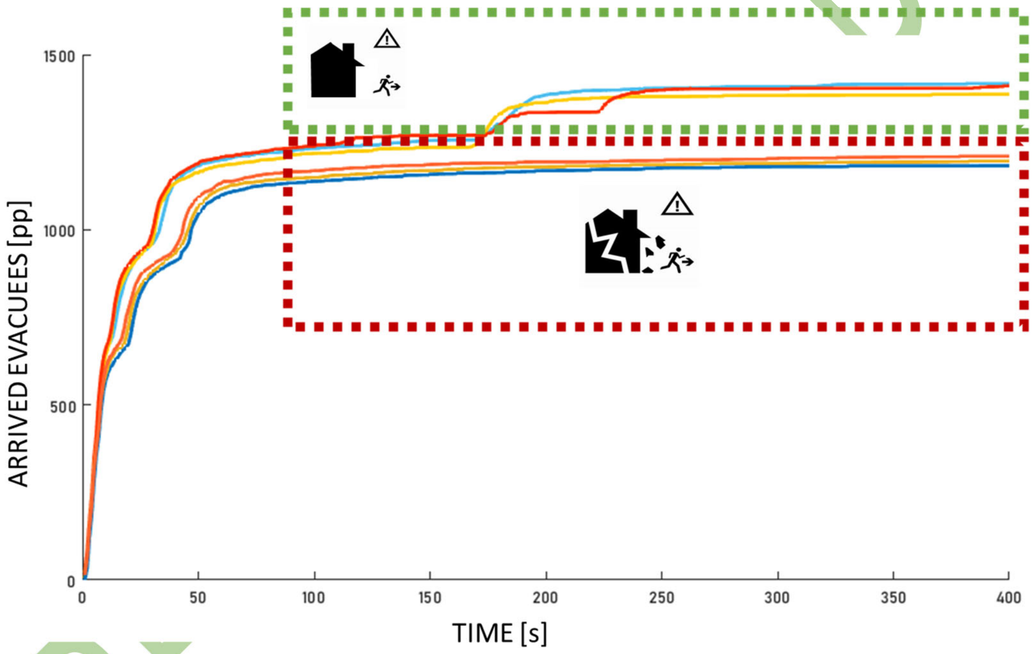

Figure 17. Evacuation curve for the Narni case study, comparing the Sb scenario (without debris) and SE1 and SE2 scenarios (with debris). The dashed boxes point out the horizontal final evacuation step in Sb (green) and SE1+SE2 (red) scenarios), highlighting that differences in the final number of evacuees exist.

Given this general outline of the process, Table 6 traces the "dynamic" (behavioural) KPIs values in the different UTCI and damage conditions, and considering the homogeneous positions of users in the buildings. Table 7 shows the percentage differences among the same damage scenarios, for the same UTCI scenario, while Table 8 shows the percentage differences between the same UTCI scenarios, for the same damage scenario.

Table 6. The "generic" simulations results (homogeneous users' position in the buildings at the starting of the process), depending on UTCI and damage scenarios.

Case studies	no UTCI			basic UTCI			1-hour UTCI		
	Sb	SE1	SE2	Sb	SE1	SE2	Sb	SE1	SE2
KPI 7	0.36	0.22	0.17	0.37	0.18	0.19	0.34	0.21	0.19
KPI 8	0.14	0.20	0.26	0.13	0.24	0.21	0.14	0.20	0.21
KPI 9	0.87	0.82	0.76	0.87	0.69	0.79	0.86	0.81	0.79
KPI 10	0.09	0.22	0.22	0.09	0.21	0.22	0.11	0.31	0.21

Table 7. Percentage differences in KPIs according to UTCI levels (risk before seismic event). The basic scenario on which the data is normalized is the Basic SB scenario, and data refers to the "generic" simulations results.

Case studies	No UTCI	Basic UTCI	UTCI 1h	No UTCI	Basic UTCI	UTCI 1h	No UTCI	Basic UTCI	UTCI 1h
	Δ% SB	Δ% SB	Δ% SB	Δ% SE1	Δ% SE1	Δ% SE1	Δ% SE2	Δ% SE2	Δ% SE2
KPI 7	0.0%	2.7%	-5.6%	-38.8%	-50%	-41.6%	-52.7%	-47.2%	-47.2%
KPI 8	0.0%	-7.1%	0.0%	42.8%	71.4%	42.8%	85.7%	50%	50%
KPI 9	0.0%	0.0%	-1.1%	-5.7%	-20.6%	-6.8%	-12.6%	-9.1%	-9.1%
KPI 10	0.0%	0.0%	22.2%	144%	133%	244%	144%	144%	133%

Table 8. Percentage differences in KPIs according to rubble (Tr= 475 y or 975 y) level. The basic scenario on which the data is normalized is the Basic SB scenario, and data refers to the "generic" simulations results.

Case studies	no UTCI			basic UTCI			1-hour UTCI		
	Δ% Sb	Δ% SE1	Δ% SE2	Δ% Sb	Δ% SE1	Δ% SE2	Δ% Sb	Δ% SE1	Δ% SE2
KPI 7	0.0%	-38.8%	-52.7%	2.7%	-50%	-47.2%	-5.6%	-41.6%	-47.2%
KPI 8	0.0%	42.8%	85.7%	-7.1%	71.4%	50%	0.0%	42.8%	50%
KPI 9	0.0%	-5.7%	-12.6%	0.0%	-20.6%	-9.1%	-1.1%	-6.8%	-9.1%
KPI 10	0.0%	144%	144%	0.0%	133%	144%	22.2%	244%	133%

In the graphs in Figure 18 it can see the comparison between the three scenarios based on the presence and type of debris and the absence of heatwaves. KPIs 7 and 8 describe the course of evacuation, the results show an opposite trend for KPI 7 and KPI 8.

In fact, the Evacuation time percentile (KPI 7 in Figure 18.g) is directly related to the time needed to reach a safe place and, considering the absence of debris (SB), evacuation times were expected to be shorter in the absence of debris, but this is not the case. The values show opposite results. In the SB layout time is longer, this is explained by the fact that a greater number of people manage to complete the evacuation than in the two cases, they slow down the process. With the presence of debris (both SE1 and SE2), the loggia area is more vulnerable to the earthquake and therefore to debris, so evacuation times of the two scenarios are more like each other and lower than Sb ones.

Crowd effects (KPI 8 in Figure 6.h), on the other hand, measure the probability of physical contact during the evacuation process and have an increasing course, opposite to what was seen previously. KPI 8 is lower in the case of SB than SE1 which is lower than SE2. As the area occupied by debris increases, the number of collisions inevitably increases as the area where people are free to move decreases.

KPI 9 (Figure 6.i), which considers the flow of users towards the centre of the square (safe area), shows a decreasing trend as the debris increases and therefore the area covered by debris. In the condition of no debris, KPI 9 does not undergo changes in the three scenarios, a symptom that the presence of a wave of color does not affect the evacuation. In the SE1 condition, evacuation reports better values with basic UTCI than no UTCI and UTCI-1h. The situation is opposite for SE2, where both scenarios with UTCI report higher indices.

The number of non-evacuees (KPI 10 in Figure 18.j) is similar between the two scenarios SE1 and SE2, while the case without debris reports a lower value. The absence of the debris allows many more people to evacuate because the evacuation routes are free of obstacles.

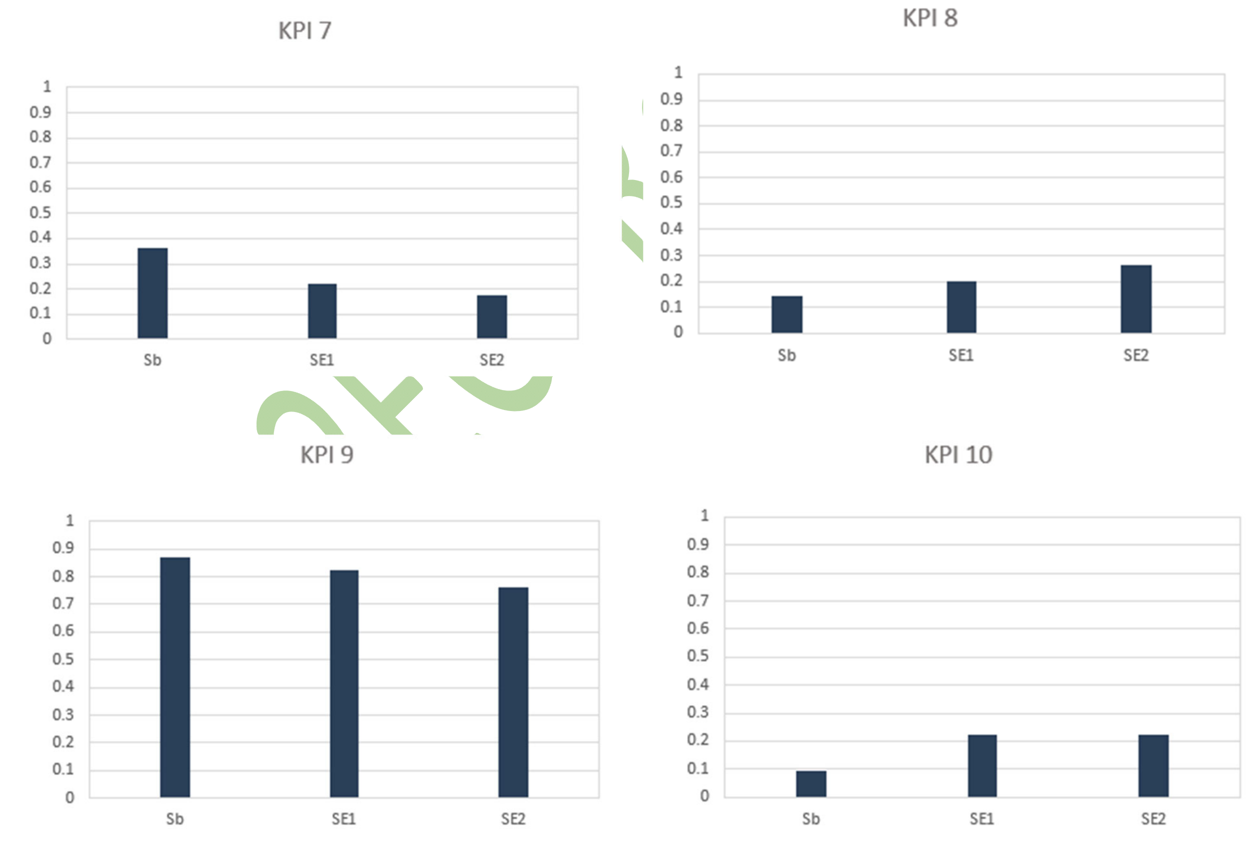

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Figure 18. Summary graphs of KPI values in the three risk scenarios: comparison between piazza dei Priori (Narni, TR) with occupied loggia without UTCI

Figure 19 shows the results of KPIs 7, 8, 9 and 10 in the case of basic UTCI, comparing the three scenarios SB, SE1 and SE2.

The results are in line with the previous ones. KPI 7 (Figure 19.g) shows the same trend as the case without UTCI; the layout without debris has higher evacuation time than others. The presence of the heat wave does not cause a substantial difference in the results; users are able to evacuate at similar times, as the number of people involved is like the case without UTCI. KPI 8 (Figure 19.h) also has similar values between the scenario without UTCI and with basic UTCI, with increasing values in cases SE1 and SE2 which correspond to those with more areas occupied by debris.

For basic UTCI case, KPI 9 (Figure 19.i) has a different trend than the previous case (no UTCI). The normalized flow has higher values in case of absence of debris (SB) and debris 975 (SE2); the intermediate case SE1 reports residual values and is the best for this KPI.

As for KPI 10 (Figure 19.j), when debris is present, there are no major differences in the trend of the graphs compared to the case without UTCI; this proves that the area of the loggia is not particularly attractive in heat wave conditions. The presence of debris results in more trapped users who do not complete the evacuation.

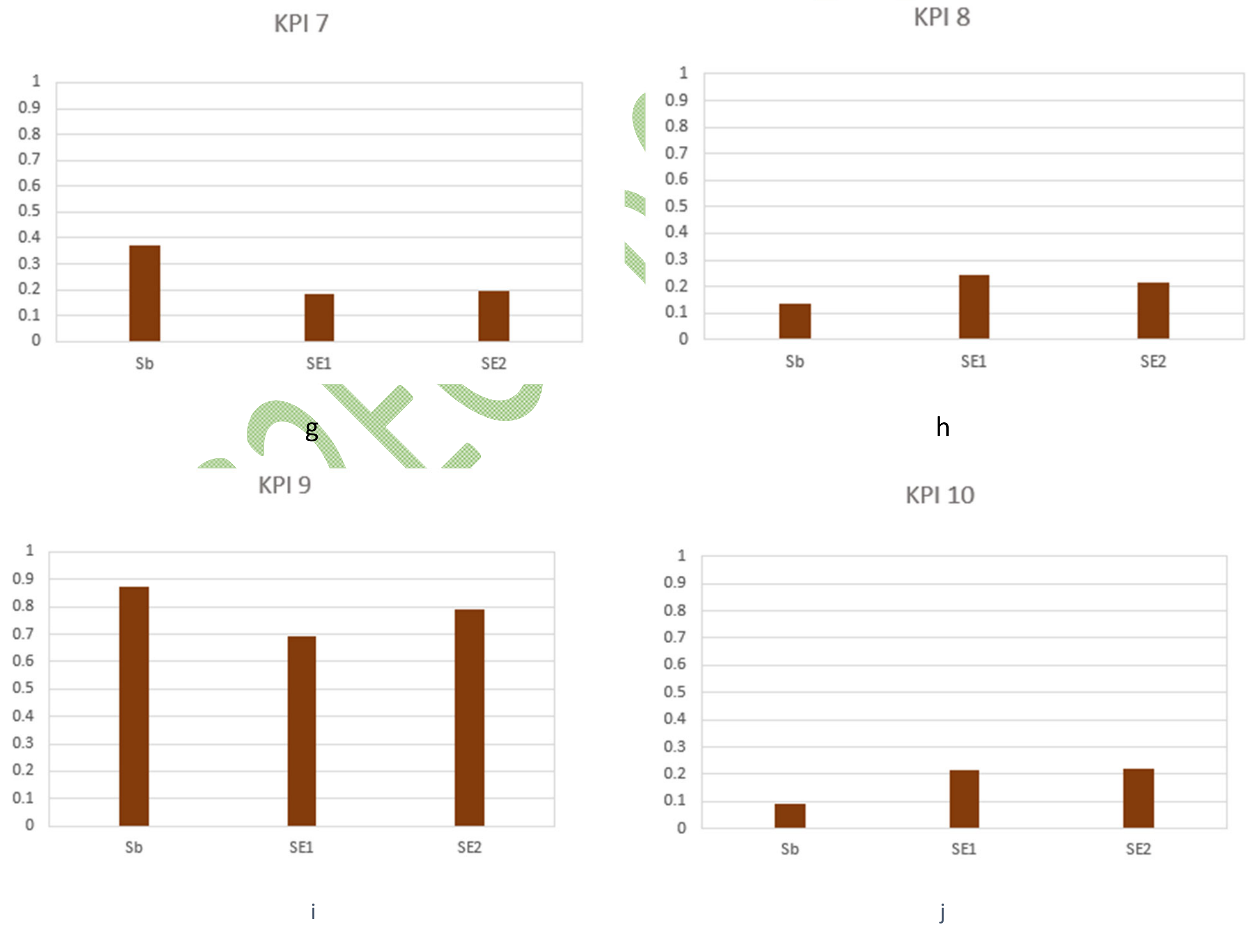

Figure 19. Summary graphs of KPI values in the three risk scenarios: comparison between piazza dei Priori (Narni, TR) with occupied loggia with UTCI

Figure 20 shows the results of KPIs 7, 8, 9 and 10 in the case of 1hour UTCI, comparing the three scenarios SB, SE1 and SE2.

The results are in line with the previous ones. 1-hour UTCI considers people coming from buildings who take longer to reach the safe area. KPI 7 (Figure 20.g) values very similar to the previous ones. For the SB UTCI-1h case it turns out to have the lowest KPI 7 value due to a smaller number of users who reach the square than the other two SB cases (basic UTC and no UTCI). In the case of SE1 the lowest evacuation times are those of basic UTCI, while no UTCI and UTCI 1-h do not report significant differences. The basic UTCI case determines lower evacuation times because reasonably the people who gather in the loggia to shelter from the heat, then move more easily towards the center of the square. In fact, in the case of no UTCI in SE1 more people are trapped, considering that they do not move preventively to solve the thermal discomfort. SE2 reports shorter evacuation times in the case of no UTCI in which users move directly towards the center of the square, without considering slowdowns due to the increase in temperature that slow them down.

KPI 8 (Figure 20.h) is increasing between SB, SE1 and SE2. Reasonably the beach could be the one in SB, where I have a greater number of users, I also have a greater area where they move, while in the other two scenarios, the debris occupies most of the surface available for evacuation. Among the three common UTCI scenarios, in the SB case the one with a lower KPI 8 value is the case of basic UTCI, albeit slightly reduced to the two. Per il caso SE1, il numero di collisioni maggiori viene registrato nel caso UTCI base, mentre per il caso SE2 nel layout senza UTCI.

For 1-hour UTCI case, KPI 9 (Figure 20.i) again reports a decreasing trend as in the case of no UTCI, in fact the values do not differ too much from those seen previously.

As for KPI 10 (Figure 20.j), when debris is present, there are no major differences in chart trends compared to the base UTCI and no UTCI; as in the previous case, in Sb the UTCI 1-h scenario has a higher value than in other cases of basic UTCI and no UTCI because a greater number of users do not complete the evacuation.

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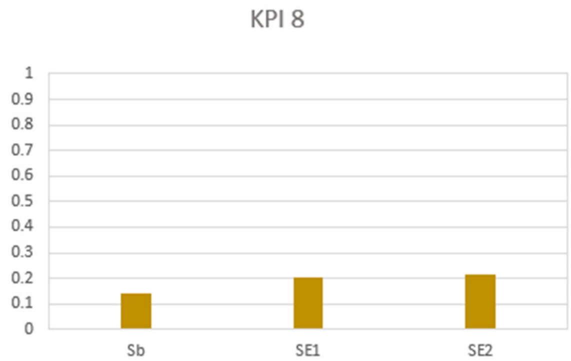

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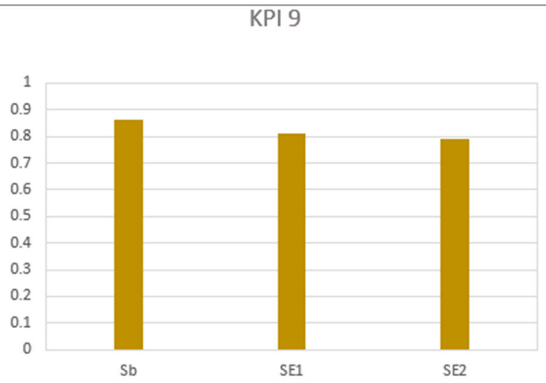

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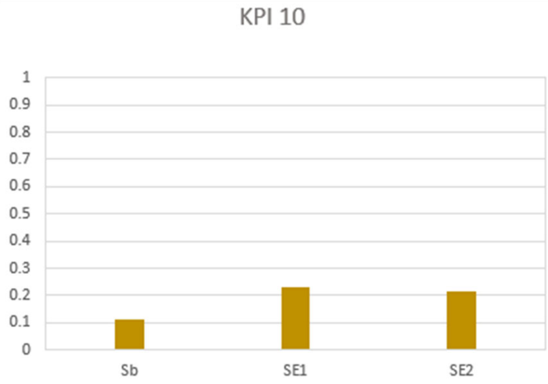

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Figure 20. Summary graphs of KPI values in the three risk scenarios: comparison between piazza dei Priori (Narni, TR) with occupied loggia with UTCI-1h

Table 9 focuses on the KPIs results considering the "updated users' positions", showing that some differences with the homogeneous conditions is noticed. From a general perspective, in comparison with Table 6, values are more similar between the three scenarios, especially in no UTCI scenarios, regardless of the damage conditions. This result underlines that the presence of people in the same starting points is more influent than the risk-effects scenarios, and thus behavioural effects are more relevant for the final KPIs assessment. In the following, a detailed comparison of results is shown.

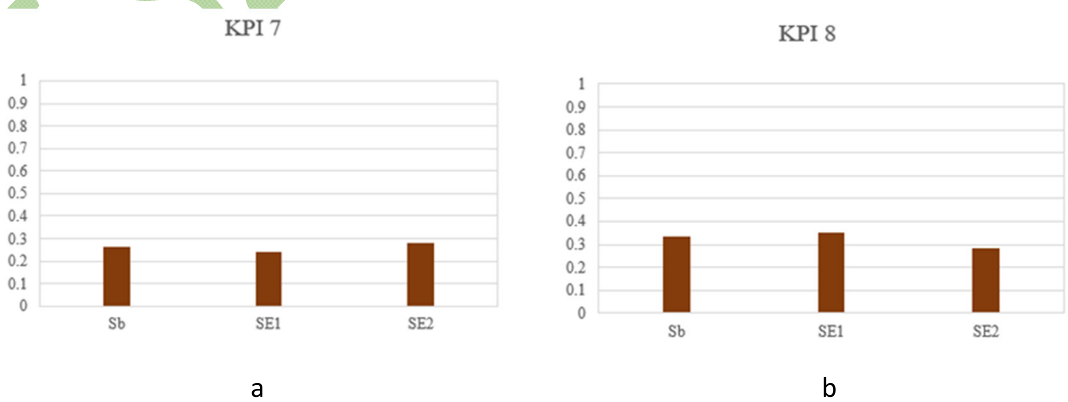
Table 9. Effects of UTCI on the evacuation-related KPIs; data refers to the "updated users' positions" simulations results

Case studies	no UTCI			basic UTCI		
	Sb	SE1	SE2	Sb	ST1	SE2
KPI 7	0.26	0.26	0.28	0.26	0.24	0.28
KPI 8	0.30	0.31	0.26	0.33	0.35	0.28
KPI 9	0.77	0.77	0.79	0.76	0.75	0.78
KPI 10	0.36	0.35	0.31	0.35	0.35	0.32

In the graphs in Figure 21 you can see the comparison between the three layouts based on the presence and type of rubble and the absence of heatwaves. KPI 7 (evacuation time) is equal for scenario SB and SE1, and higher for SE2. The possibility that with an earthquake with Tr = 475 years, the rubble occupies that area, does not involve variations in the speed of evacuation compared to an earthquake without rubble. In the case of Tr=975 years, with a potential larger area covered by debris, the time is longer. As expected, KPI 8 has the opposite trend compared to KPI 7. Very similar between SB and SE1 (with SE>SB considering that the presence of debris favours greater collision), it decreases in SE2. In SE2, therefore, the collisions between users are lower in relation also to KPI 10 (% evacuated) which decreases from SB to SE1, up to the minimum in SE2. Considering KPI 10 and 7, it is reasonable to obtain that KPI 9 (normalized flow), is greater in SE2, when evacuation times are greater. SE2 is the riskiest scenario in the no UTC condition.

Figure 21. Summary graphs of KPI values in the three risk scenarios: comparison between piazza dei Priori (Narni, TR) depending on the damage scenario; data refers to the "updated users' positions" simulations results and considers no UTCI conditions

The results of user exposure analysis in the basic UTCI case are shown in Figure 22. The evacuation time (KPI 7) has the minimum in the SE1 condition and the maximum in the SE2 condition, while Sb has an intermediate value. The KPI 8 (shocks), increases between the condition of absence of rubble and rubble 475, and then lowers in the case of rubble 975. KPI 10 (% evacuated) also follows the same trend (SB=SE1>SE2), while normalized flow (KPI 9) follows KPI 7, with a decrease in coefficients between SB and SE1 and an increase in SE2.



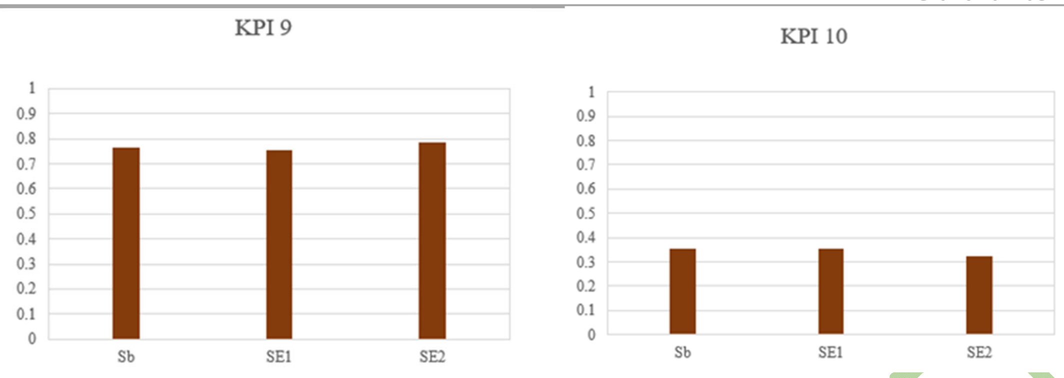


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Figure 22. Summary graphs of KPI values in the three risk scenarios: comparison between piazza dei Priori (Narni, TR) depending on the damage scenario; data refers to the "updated users' positions" simulations results and considers basic UTCI conditions

3.3 Final metrics and multi-risk vectors

The final SLOD and SUOD risk metrics are derived from the weighted sum of the calculated KPI values using the weights defined in D424 for BET.

The graphs in the following figures show the final metrics for the SLOD risks, from which it is clear what has already been stated in this section. In general, for the risk of heat waves (Figure 23), the case studies show higher risk values than the corresponding BET, although they are very similar to each other.

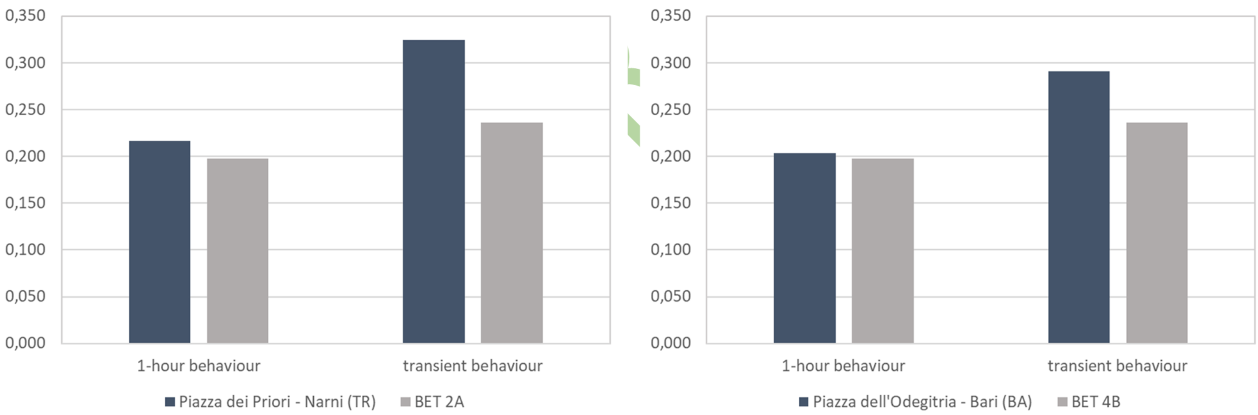

Figure 23. Final heat wave risk metric: comparison between the case study and the associated BET.

For the risk of air pollution, the opposite is true, with BET values much higher than AQI (Figure 24).

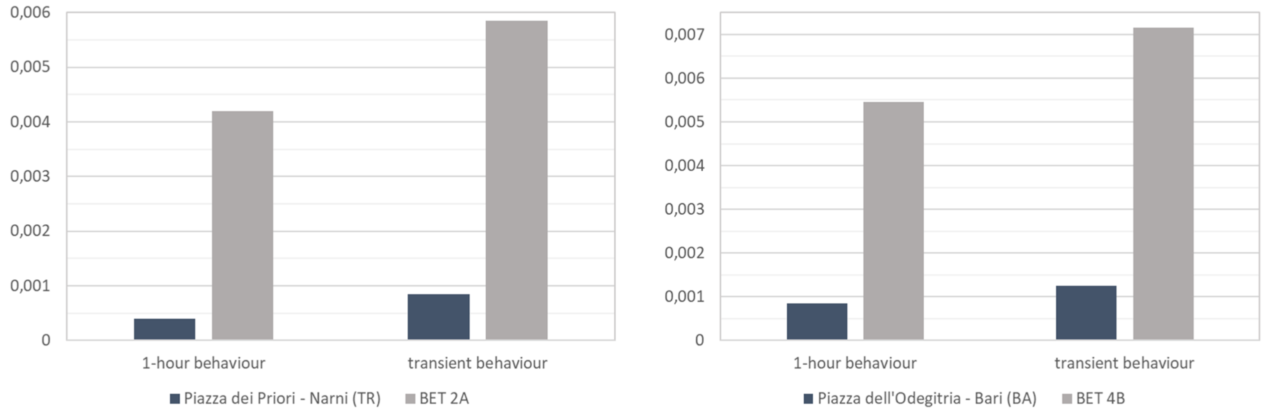

Figure 24. Final air pollution risk metric: comparison between the case study and the associated BET.

Knowing the SLOD risk scenarios, the simulation approach "SLOD-to-SUOD" was applied to assess the terrorist risk for the case of Piazza dell'Odegitria and the seismic risk for Piazza dei Priori.
The Figure 25 shows the simulation results for Piazza dell'Odegitria for the considered cases of terrorist attack, namely "false alarm" (as base scenario Sb), weapon attack (ST1) and vehicle attack (ST2), through the metric. The graph below shows that the risk difference with the corresponding BET 4B is limited (within 25% for Sb and 10% for ST1 and ST2), confirming the possibility of agreement between typological and real scenarios and therefore the validity of using BET to carry out rapid and preliminary analyses. However, it should also be noted that the risk metric for the case study is slightly higher than that of the BET, since in the real case, unlike the ideal one, there are two special buildings (two churches) that increase the number of potential users present in the square, thus alternating the congestion in the outdoor spaces.

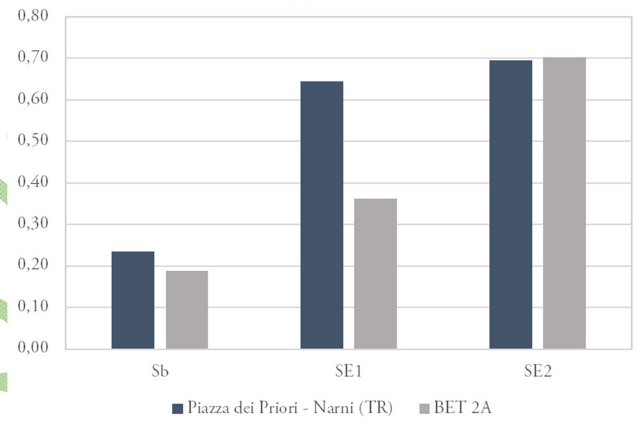

Figure 25. Final terrorism risk metric: comparison between the case study and the associated BET.

The Figure 26 shows the result of the final seismic risk metric for Piazza dei Priori, whose indicator can vary between 0 (minimum risk) and 1 (maximum risk), calculated for the three basic conditions (without the effect of the event, Sb), TR=475 (SE1) and TR=975 (SE2), compared with the typological application to BET 2A. As expected, the value of the metric increases with the severity of the earthquake impact, and the comparison shows that the extreme scenarios Sb and SE2 have essentially equivalent conditions. However, for the intermediate scenario SE1, there is a significant difference between the case study and BET, and a similarity of impact to the SE2 condition in the case study itself (E difference of about 10%). The result is that the prediction of debris at TR=475 years is not significantly different from that at TR=975 years. As can be seen in Figure 8.C and Figure 8.D, the extensive debris potentially reduces the free surface (as an essentially undisturbed safe area) already from the SE1 scenario, and therefore implies similar conditions in the interaction between users in the process of exiting to the open space of the square.

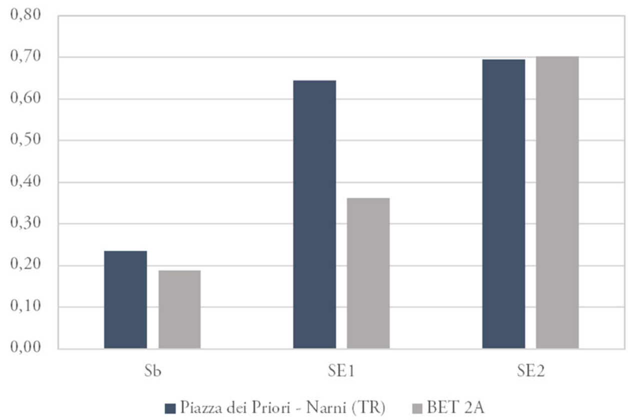

Figure 26. Final seismic risk metric: comparison between the case study and the associated BET.

Finally, multi-risk vectors are defined to obtain an overview of the risk and to facilitate the reading and comparison, especially in function of the future analyses carried out on the case studies. The method to define these vectors is given in D424 for BET.

	Piazza dell'Odegitria	BET 4B	Piazza dei Priori	BET 2A
S_{TOT}	0,263	0,233	0,361	0,303

Figure 27. Matrix of multi-risk vectors for risk. The gradient represents the overall risk, allowing comparison between case studies and associated BETs. From lowest risk (dark green) to highest risk (red)

The matrix in Figure 27 shows the final multi-risk vectors resulting from the multi-risk combinations for each case study. The case studies are in both cases worse than the corresponding BET, as expected from the results of the analyses carried out in this document. The final risk value of Piazza dei Priori is higher than that of Piazza dell'Odegitria, as confirmed by the results of the associated BET. This apse is more influenced by the size of the square, which determines a greater number of people in Piazza dei Priori. The numerous activities in the square also contribute to the increase in the number of visitors, which in Piazza dell' Odegitria is almost exclusively determined by religious tourism, given the presence of two churches.

4. Conclusions and remarks

The results obtained confirm the validity of the methodological approach based on the use of synthetic indicators (KPIs) to assess risk in an open space.

The application of this approach to real-life scenarios has enabled us to evaluate the method's effectiveness in complex situations, including the presence of commercial activities and special buildings on the ground floor of buildings (which have outdoor seating areas facing public spaces). The relationship between user behaviour, the environment, and density are intricately linked and rely heavily on the typical usage of a public square. This relationship has significant real-life implications since user habits can alter the baseline scenario, leading to a significant change in risk assessment. For the case study of Narni, the loggia in front of the town hall is a significant factor, particularly during the summer when many people gather in this area to benefit from the shade instead of being dispersed throughout the square.

The most noticeable discrepancies between the case study and the corresponding BET exist due to the familiarity with a space and the adaptability of users. Consider, for instance, the situation of Odegitria Square connected with BET 4B. Although the similarity with the BET is very close, a small rectangular square, the presence of two churches, one of which is the cathedral of Bari, cannot be ignored. In the case of BET, the number of users visiting the special building is fixed at 480, calculated based on the average size of the same building as deduced from the analysis of the surveyed squares. While the number of users varies according to specific use and the surface area of the Special Building, which, in the case of Bari, is approximately 2000 square metres (almost double the size of the square), Piazza dei Priori is a bustling square with numerous places of interest for the community.

The building houses some of the classrooms of the University of Rome, the town hall, the theatre, as well as various bars and shops. The comparison with BET (2A) was not as straightforward in this case due to the elongated and narrow "L" shape of the site, which places it within the convex morphological typology that was not investigated by the project during the BET definition phase.

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